A SYSTEMS ANALYSIS OF APPLICATIONS OF EARTH ORBITAL SPACE TECHNOLOGY TO SELECTED CASES IN WATER MANAGEMENT AND AGRICULTURE

Volume II - Technical Report

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A SYSTEMS ANALYSIS OF APPLICATIONS OF EARTH ORBITAL SPACE TECHNOLOGY TO SELECTED CASES IN WATER MANAGEMENT AND AGRICULTURE

Volume II - Technical Report

PRC R-1224

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By

Planning Research Corporation

FOREWORD

This study has been completed in partial fulfillment of a request by the Bureau of the Budget to the National Aeronautics and Space Administration (NASA) for a systems analysis of several specific applications of satellite-based remote sensing to earthbound problems. The study was funded and managed by the NASA Office of Space Science and Applications (OSSA) and was coordinated and reviewed by the interagency Earth Resources Survey Program Review Committee (ERSPRC). The committee is chaired by a NASA representative and currently includes representatives from U.S. Departments of Agriculture, Interior, Commerce, and Navy. The prime contractor, Planning Research Corporation (PRC) was assisted by the Willow Run Laboratories of the University of Michigan under a subcontract to supply technical data and judgments on sensor capabilities.

The focus of the study was formulation and evaluation of feasible future operational system concepts for applying satellite-based remote sensing to improve the management of specific water resource and agricultural activities. These future operational concepts were assumed to follow the present research and development time frame of the NASA-user agency Earth Resources Survey Program. It was recognized at the outset that considerable research and development would be required before any such future operational concepts could be realized. It was, however, the principal purpose of the study to assess the position that future operational space-assisted ERS systems concepts were of sufficient promise to warrant rapid development of experimental Earth Observations satellites known as Earth Resources Technology Satellites (ERTS)

The scope of the present study required emphasis on concepts for using space technology rather than on improvements not requiring assistance from space. However, it was clear that any satellite-assisted information system concept should be compared with improvements not using satellites. In addition, it was expected that any system using satellites would support and complement many of the existing or planned

user agency systems and procedures. Thus, while specific alternatives to satellite-assisted information systems were evaluated, the scope of this study did not permit evaluation of integration with all user agency systems or of all alternative programs available to the user agencies. This study does present a concept for a satellite assisted information system, an estimate of the expected costs along with the expected benefits, and a comparison with some selected alternatives.

As prime contractor, PRC wishes to express its appreciation to the organizations associated with ERSPRC for assistance through ready access to knowledgeable personnel who provided data and guidance vital to the success of the study. In the final phase of the work, ERSPRC (and its Benefits Studies Subcommittee) participated in a detailed review and criticism of the complete final report. This review, however, does not imply endorsement of the system configuration details or cost-benefit dollar values. The conclusions and recommendations contained in this report are those of the contractor.

The NASA Project Officers were Mr. J. Robert Porter and R. Robert A. Summers. The PRC Project Managers were Dr. Allen H. Muir and Mr. John F. Magnotti, Jr.

The final report on this study is presented in two volumes. The full description of the work is contained in Volume II, Technical Report, and is supported by nine appendixes and a bibliography. The appendixes are the following

Appendix A—User Sensor Model-Hydrology

Appendix B—Hydrological Models

Appendix C—System Operation and Benefits

Appendix D—Satellite System Description and Costs

Appendix E—Alternative Information Systems

Appendix F—Noninformation Alternatives

Appendix G—User Sensor Model-Agriculture

Appendix H—Wheat Production Management

Appendix I —Wheat Rust Control

Volume I, Technical Summary, is a much briefer description of the significant aspects of the work Detailed descriptions of the calculations and procedures referred to in Volume I will be found in Volume II

ABSTRACT

A systems analysis of three of the many uses of space technology for earth applications was undertaken by the Planning Research Corporation The work followed a uniform methodology developed in an earlier report, PRC Technical Report R-1218 The case studies related to

- The management of the regional demand and supply of water (emphasizing the generation of hydroelectric power, flood control, irrigation, and recreation)
- The management of the world wheat crop (emphasizing the impact of fluctuations on the United States as the major exporter)
- The control of wheat rust, a principal cause of wheat losses in the United States and abroad

A conceptual system was designed that links user information needs to the specifications of satellite-borne sensors and the interpretation and dissemination of results to the users

The satellite, sensors, communications, data processing, and dissemination system required will have to be supported by developmental research, however, it appears that no significant basic research in the hardware state-of-the-art will be necessary Proof of operational effectiveness of the multispectral scanner, the multispectral television, and the synthetic aperture radar at satellite altitudes and the incorporation of the relevant earth science models into the integrated system must be undertaken

The estimated total system costs, including R&D, investment, and 20 years' annual operating costs total $1 34 billion The United States' benefits from the three cases were estimated at 10 5 billion for the 1970-90 period, and world benefits were estimated at $50 billion The benefits accrue to power users, residents of flood plains, farmers, other individuals, and the general public

The four-satellite system proposed in the report could be deployed solely for wheat production management alone, but the benefits could be

realized with fewer satellites and no radar The satellite system makes it possible to monitor world wheat production to permit optimal United States adjustments

The wheat rust case requires more frequent monitoring (every 12 hours) and the use of radar Aircraft overflights offer a lower cost alternative than a satellite system used solely for wheat rust control

The water management case requires 6-hour coverage and the full use of the satellite system The cost-benefit ratios are substantial, and the satellite is superior to aircraft and other alternatives if a major portion of the United States' river basins are covered

Viewed in another perspective, however, the multipurpose satellite system requiring 6-hour observations, the multispectral scanner, TV, and radar can be supported by the water management case alone That system could then generate, as by-products, the benefits from the wheat management and wheat rust cases

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I INTRODUCTION

The usefulness of satellites for such purposes as weather monitoring and communications has already been established There is now reason to believe that, with more complex sensors, satellites and the equipment carried by them can be used to gather information of benefit in such areas as agriculture and water management

Several departments and agencies of the federal government, particularly the National Aeronautics and Space Administration, the Department of Agriculture, the Department of the Interior, the Department of Commerce, and the Department of the Navy have been interested for some time in possible earth applications of the space program and in the costs and benefits of such projects Assessment of the potential costs and benefits of satellite applications is of crucial importance in determining whether experimental satellite systems should be developed to an operational stage It is necessary first to determine whether the expected benefits of applications programs are high enough to support the expenditures associated with the program It is next necessary to compare the satellite-assisted system with alternative ways of supplying the same information (e g , aircraft) Further, it is necessary to know how the ratio of benefits to costs of the satellite-assisted system compares with the cost-benefit ratios of projects that are obvious competitors for financial support

A system analysis is necessary to support these comparisons, benefits and costs must be developed for a feasible system State-of-the-art components must be incorporated to hold down costs and permit early deployment Insofar as R&D outlays are required, these need to be defined and incorporated into the analysis A system concept can be and is developed Many tradeoff studies will be necessary before deciding on the final concept Sensitivity analyses in this study indicate directions of such tradeoff studies Finally, major R&D directions are indicated, particularly relative to the space and earth sciences

This study represents a continuation of work done by PRC under contract No NASW-1604 Under the initial contract, a methodology for analyzing earth applications of satellites was developed and applied in several test cases A number of potential users of a satellite information system were identified, the benefits expected to accrue to users in various application areas were projected, and the applications areas were ranked according to size of expected benefits

In the present study, the basic methodology developed earlier has been extended and applied to the conceptualization of an operational information system for two highly ranked applications areas· water management and agriculture Analysis has been aimed at formulating an operational system concept, identifying potential problems, estimating research and development requirements, and projecting the probable costs and benefits of a system that might be operational in the mid-1970's

The technology exists to launch space vehicles, to put them into precise orbits, power and stabilize remote sensors, and to communicate observed data on earth phenomena back to earth for analysis, interpretation, and dissemination In this study, the ultimate user of information has been the focal point for designing the operational information system The user's information needs have determined the choice of sensors, observation frequencies, data interpretation methods, and the nature of the information dissemination system The relationship among user information needs, the specifications of various elements of the information and management system, and the estimation of system costs and benefits is illustrated in Exhibit I-1 This flow diagram of the analytical methodology is taken from PRC Report R-1218, developed under the earlier contract with NASA

Actually, in developing the system analysis, it is necessary to iterate through Exhibit I-1 It is not possible to move straight through the methodological flow diagram from start to finish Several important problems emerged which had to be solved through repeated iterations The sensors are limited as to ability to identify and measure Techniques of pattern recognition, the advantage of repeated observations, and various corroborating techniques were required to cope with sensor

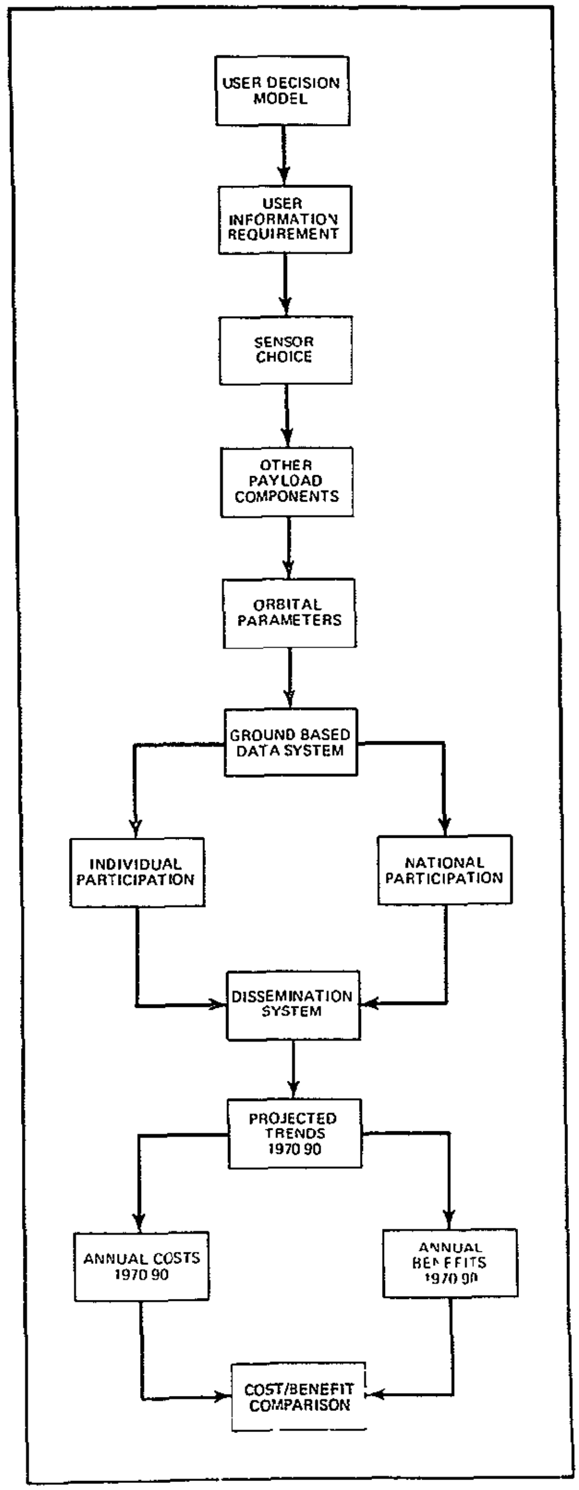

EXHIBIT I-1 ABBREVIATED METHODOLOGICAL FLOW DIAGRAM

limitations Initial impressions indicated that the sensor data that might be developed would be overwhelming from a transmittal, processing, interpreting, and dissemination point-of-view The solution to this problem obviously is a series of sampling techniques that yield information sufficiently reliable for decisionmakers Models and scenarios were required to place sensors, sampling, and information requirements in their proper context In particular, they also allowed us to make tests of sensitivity

The water management case is treated first and in most detail Many of the results and concepts developed therein were applicable to the agricultural cases (and probably to other cases not herein studied) and were not repeated in detail in the wheat production and wheat rust studies

After defining the problem and approach, the sensors and earth sciences submodels were integrated into a typical subbasin model for water management This model demonstrates the interrelationship of the various components aimed at estimating stream flows for dam managers (The same work can help project water requirements as well as demands) A detailed scenario is also developed to show the dynamic interrelationship of observations, calculations, and decisionmaking

The product of the subbasin modelizing would be the Moving Forecast Scale (MFS) with its probable error envelope used to predict stream flows through to the end of the water season It was not possible in the present study to quantify the MFS The hydrologic framework in this study is based on a simplistic conceptualization of hydrologic forecasting and modeling The computerized hydrologic models now in use by the Bonneville Power Administration and the U.S Army Corps of Engineers (CE) are sufficiently complex to be beyond the scope of the study to conduct sensitivity analyses of these models to determine how they might best be improved by satellite sensing Further research is required to establish signatures, resolutions, and other characteristics of sensors at operational altitudes and to quantify the earth science submodels of the subbasin model It appears reasonable to assume that the MFS can be developed and that high overall system accuracies can be

obtained Assuming the development of the MFS, it is possible to integrate the satellite-assisted information into the water management system through a simplified river management model This was done to estimate the potential benefits of a satellite-assisted program The benefits that subsequently emerged clearly justify the R&D program required to realize the benefits of the new satellite-assisted information system

Very similar techniques were employed in developing the agriculture cases Much of the same type of analysis is repeated in order to conceptualize a satellite-assisted information system to support the management of wheat production (relative to the inventory and yield of wheat) and of the stress problem (involving wheat rust and other fungi) Scenarios are developed to show the dynamic interrelationships of observations, estimating techniques, and decisionmaking

Only a few citations to reference materials are found in this Volume References are cited completely in the Appendixes

II WATER MANAGEMENT CASE

The basic water management problem is one of forecasting flows of water which are often highly variable and may simultaneously affect hydroelectric power generation, irrigation, flood control, navigation, and recreation This study concentrates on one particularly significant water management case, that of the Columbia River and its tributaries which drain the Northwestern portion of the United States In this area, water management is oriented toward multiple purposes and is performed by a number of agencies, including the Bonneville Power Administration, the Army Corps of Engineers, and the Bureau of Reclamation, as well as other public and private groups The Columbia River Basin case serves to point up clearly how the interests of various users of water may differ considerably and often conflict

The water management section of this report is divided into eleven subsections The first, Subsection II A , describes the results of a survey on user information needs A user-sensor model, relating user information needs for satellite-sensor capabilities, is set forth in Subsection II B Subsection II C gives the details of two hydrological forecasting models designed to quantify and evaluate hydrological and meteorological data obtainable by satellite and to use these data to generate information on future reservoir levels It is this information, the output of the hydrological forecasting models, that is fed into the management area, where it is combined with the policies and other constraints from the power, irrigation, flood control, navigation, and recreation area Throughout this system, meteorological data are continually being used to complement sensor observations to achieve the highest possible levels of system accuracy

Subsection II D describes the water management problem as it relates to the four key water use areas hydroelectric power benefits (Subsection II D 1), irrigation (Subsection II D 2), flood control (Subsection II D 3), and navigation and recreation (Subsection II D 4) The information system configuration and the ways in which a better information system could improve management in each of these areas of water use are

analyzed, and the benefits to be derived from improved management are projected. Total water management costs and benefits for the Pacific Northwest are summarized in Subsection II H In Subsection II I, water management benefits for the Pacific Northwest are extrapolated to the rest of the United States In order to make possible a cost-benefit analysis, total system costs are described in Subsection II G Finally, for comparison purposes, information and noninformation alternatives are summarized in Subsections II J and II K , respectively

A Information User Survey

Several tasks are undertaken in this section In developing a user-oriented information system it is first important to identify the major potential users of the new information. This in turn forms the logical starting point for a discussion of management decisions of such users in order to identify how the new information will be used under present or projected management rules for the benefit of the Pacific Northwest Extensive discussions were held with the identified users in order to develop the user-sensor model to be found in the next section and the decision models subsequently described

In the user survey another task was undertaken It is appropriate to establish if potential users themselves see a need for new information and what volume and type of information they indicate is needed Major power users were interrogated and managers associated with flood control, navigation, recreation, and irrigation were approached during the course of the study The overall results are presented in this section

Exhibit II-1 is a schematic representation of the current management information system in the Columbia River Basin In general terms, water management in the basin is performed by three main groups Bonneville Power Administration (BPA), non-Federal power producers and brokers (non-feds), and the United States Army Corps of Engineers (CE) Although several of the larger dams were constructed by the Bureau of Reclamation, Department of the Interior, primarily for irrigation purposes, control of these dams has been delegated to BPA

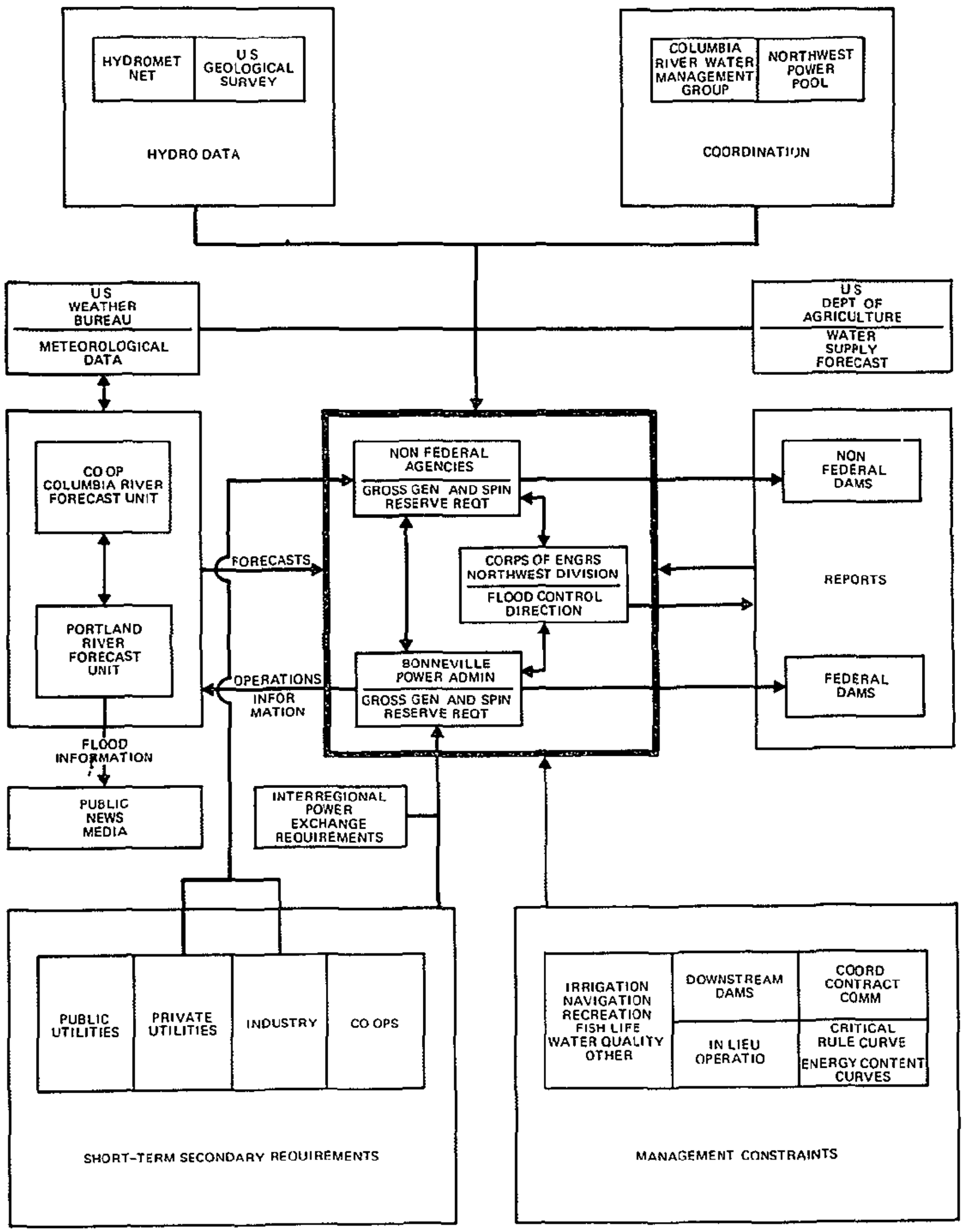

EXHIBIT II-1 COLUMBIA RIVER BASIN HYDRO INFORMATION-DECISION SYSTEM

with the understanding that a specified firm amount of water be allocated each year for irrigation The non-feds are interested almost entirely in power production and marketing The CE is responsible for all flood control measures within the river system

Operation of the river basin's water is coordinated by the Pacific Northwest Coordination Agreement All Federal, State, and local organizations, public and private, who are concerned directly with power production and water management, are signatories to the agreement The Coordination Contract Committee (CCC), a group formed from member representatives, coordinates operations in accordance with the terms of the agreement The most important job of the CCC is to prepare the operating program that sets the reservoir rule curves and energy requirements for each year The CCC also is responsible for readjusting variable energy content curves from January through July

In addition to the CCC group, coordination of water management is of interest to the Columbia River Water Management Group and the Northwest Power Pool, as well as the recently created Columbia River Basins Commission The Columbia River Water Management Group is made up of representatives of Federal and State agencies and acts only in a coordination and advisory role It includes representatives not only of agencies actually involved in water management but also of other agencies that are interested in and affected by water management the Bureau of Reclamation, the Federal Power Commission, the Public Health Service, and the Department of Commerce The Northwest Power Pool is now an informal coordinating group of power producers, although prior to the Pacific Northwest Coordination Agreement it was the primary agency for coordination of water management and power production in the Northwest The Columbia River Basins Commission, a relative newcomer, deals mainly with studies concerning the Columbia River Basins The Commission is funded jointly by the Federal Government and the five northwestern states, Washington, Oregon, Idaho, Montana, and Wyoming

Private industrial establishments concerned with power production are comprised largely of the aluminum producers in the area

Led by Alcoa, Kaiser, and Reynolds, these companies account for the bulk of industrial power requirements in the Northwest

The information system is characterized by a multiplicity of data sources and forecasting procedures Water runoff forecasting is a requirement for all power producers and ranges from very informal daily estimates to formal forecasts prepared either by power producers themselves or by private agencies purchasing power on contract Although there is a free exchange of hydrological and meteorological data among interested parties, variations in forecasting procedures produce wide variances in individual forecasts of water availability The Portland River Forecast Unit by law is required to send flood information to the public news media Although other interested groups have been invited to participate, the Cooperative Columbia River Forecast Unit is presently staffed only by personnel from the Corps of Engineers and the U S Weather Bureau A modest amount of automation exists to support forecasting, mostly in the form of computerized models used by BPA and the Corps of Engineers

Operational direction and monitoring of Federal dams for power production originates in BPA The Corps of Engineers, during the flood season, assumes primary management of the Columbia Basin and issues flood control direction Non-feds, in coordination with BPA and CE, operate their dams with the stipulation that flood control directions have priority during the flooding season

In recognizing the need to discuss user interests with users, a series of information user surveys was conducted These surveys were designed to cover a reasonably broad spectrum of government and nongovernment groups who are potential users of the satellite-assisted information system Because the system would be applicable to other areas of the United States, discussions were also conducted with interested parties in California and the Northeast

In-depth interviews were conducted in the Northwest with officials of public and private utility companies The most important findings from these surveys are summarized in Exhibit II-2 The survey pointed up strongly that there is solid consensus among users that

POWER COMPANIES (Public and Private Utilities)

City of McMinnville	Puget Sound Power & Light
Cowlitz County PUD	Seattle City Light
Pacific Power & Light	Tacoma City Light
Portland General Electric	Washington Water Power Company

Q WHAT IS THE COMPANY'S RELATIONSHIP WITH BPA?

A. All companies are party to the Pacific Northwest Coordination Agreement water management because of the contractual nature of the relationship is a highly coordinated enterprise Public and private utilities are in no way subordinate to the Bonneville Power Administration although Bonneville's mandate for power marketing is recognized clearly System relationships among power companies are so complex that a distinction cannot be drawn between systems interior or exterior to federal dams on the Columbia River main stem.

Q WHAT IS THE DEGREE OF DEPENDENCY ON FEDERAL DAMS (KW POWER PURCHASES)?

A. Power purchases from BPA vary from dumped power only (Washington Water Power Company) to 100 percent (Cowlitz County PUD and the City of McMinnville Water and Power Company)

Q WHAT IS THE COMPANY'S WATER STORAGE CAPACITY?

A Water storage capacity varies however all producers are required to share costs of upstream reservoirs by Federal Act.

Q CAN THE COMPANY OPERATE EFFECTIVELY AND EFFICIENTLY FROM WATER FLOW AND METEOROLOGICAL INFORMATION SOLELY FROM THE FEDERAL DAM?

A Because of interior relationships and the fact that systems cannot be defined clearly as interior or exterior to the federal dams the same information is required by all power producing companies

Q WHAT INFORMATION CURRENTLY IS RECEIVED BY AND FROM BPA?

A BPA concurrently produces daily and monthly forecasts which are disseminated to all parties to the power contract. It should be emphasized that information is exchanged freely and without reservation by all groups concerned with power production in the Northwest.

Q WHAT MANAGEMENT TECHNIQUES ARE USED IN THE DECISION TO OBTAIN OR PRODUCE POWER?

A All parties to the coordination agreement use the rule curve operation as the primary water management technique

Q HOW MIGHT MORE ACCURATE AND TIMELY HYDRO AND METRO DATA ASSIST MANAGEMENT?

A. Better information in all cases would assist in obtaining optimal use of the water available All companies were concerned with informational requirements and by and large lack precise data upon which management decisions can be made This situation is reflected in the extreme conservatism practiced in water management and in the fact that several power producers spend significant sums of money to retain private meteorological and hydrological forecasting agencies

Q TO WHAT DEGREE ARE FORECASTING OR MANAGEMENT PROCEDURES AUTOMATED?

A. Almost no automation of forecasting or management procedures exists in the private community as opposed to BPA In some cases computer support is available but is currently not being used for these purposes

Q IS ANY TYPE OF FORECAST MADE EITHER OF NATURAL CONDITIONS OR POWER?

A. Forecasting ranges from elaborate extended forecasts produced by private consulting services to informal daily estimates made by staff hydrologists or system operators In only one case Seattle City Light was the forecast used rigidly as a management tool. In all other instances forecasting was used to supplement judgmental management.

Q HOW WILL INFORMATION NEEDS DIFFER IN THE FUTURE?

A Because of greater power demands and the increasingly cyclic nature of the river informational needs will tend to increase throughout the next decade It will be necessary to forecast internal streamflows into the total basin as well as natural streamflows into interior and exterior subbasins in order to provide information in sufficient detail to be usable by the total power producing spectrum in the Northwest.

EXHIBIT II-2 SUMMARY OF MAJOR FINDINGS OF INFORMATION USER SURVEY

ALUMINUM INDUSTRY

Aluminum Company of America
Kaiser Aluminum and Chemical Corporation

Q HAVE POWER REQUIREMENTS BEEN MET OPTIMALLY? DOES POWER SUPPLY MATCH LOAD REQUIREMENTS OR ARE THERE PROBLEMS?

A In both cases power requirements have not been met optimally Past demands exceeded the power available and although sufficient power is available at the present time power requirements forecasted through the next decade indicate possible power shortages occurring during that period In one case Alcoa the company was forced to participate in the construction and management of the Rocky Reach Dam after a failure by BPA to provide the level of power projected before construction of the Alcoa plant at Wenatchee Washington

Q WOULD MORE EFFECTIVE SECONDARY POWER SMOOTHING ASSIST PRODUCTION PLANNING?

A Secondary power smoothing would materially assist production planning At present both aluminum producers are in effect gambling by buying "provisional" power and attempting to purchase a portion of the spinning reserve by agreeing to accept short power outages in case of system emergencies

Q DOES FORECASTED POWER AVAILABILITY AFFECT THE PLANNING OF PRODUCT MIX OR VOLUME?

A Power availability forecast would be useful in deciding where a particular pot line might most economically be shut down Product mix is not affected since large amounts of power are needed only in the production of pure aluminum

Q WHAT ARE THE EFFECTS OF A SHORT TERM BROWNOUT ON PRODUCTION?

A Power outages in aluminum pot lines can be catastrophic in terms of costs if the line is out for more than 4 or 5 hours with no warning The resulting 'frozen' pots would necessitate almost complete reconstruction of the pot line

Q HOW LONG DOES IT TAKE TO SHUT DOWN A POT LINE? TO RESTART? WHAT ARE THE COSTS INVOLVED?

A An immediate power stoppage would of course result in immediate cessation of aluminum production in the line however pot lines can be prepared for planned shutdown in 5 to 10 hours The procedures involved are designed primarily to insure efficient restarting If pot lines are frozen as a result of unplanned and extended power outages restarting procedures are laborious and very costly Time and costs are dependent upon a great many variables and cannot be stated in general terms

Q WHAT INFORMATION CURRENTLY IS BEING RECEIVED FROM BPA? IS IT ADEQUATE FOR MANAGEMENT NEEDS?

A There is a total information exchange with BPA in terms of power availability and hydrological data as required

IRRIGATION

Del Monte Corporation

Q WOULD MORE ACCURATE HYDROLOGICAL AND SEASONAL WEATHER FORECASTS AND 30-DAY FORECASTS ASSIST MANAGEMENT?

A Industries such as the Del Monte Corporation in the Northwest are interested principally in the meteorological forecasts from 2 weeks to 6 months in the future

Q HOW WOULD BETTER SHORT-TERM FORECASTS AND SOIL MOISTURE CONTENT INFORMATION IMPROVE EFFICIENCY?

A Hydrological and meteorological information is most important in terms of harvesting Short-term forecasts of wind velocities and frost would be most valuable Surface soil moisture content is of little use since this information is obtained immediately and locally by the farmer Soil moisture 2 to 3 feet underground is critical

Q WOULD BETTER HYDROLOGICAL INFORMATION AFFECT DECISIONS REGARDING PRODUCT MIX TIMING OF PLANTING AND HARVESTING OR PRIORITY OF PLANTING?

A Better information would not have a significant effect on crop mix planting or harvesting in the Northwest because of the abundance of water It is interesting to note however that power producers would profit by water information in that water now held for irrigation because of uncertain data might well be released for power production Product mix is a function of plant capacity and harvest sequence However predictions of ideal conditions could result in less total crops being planted

Q WOULD BETTER INFORMATION AFFECT DECISIONS REGARDING CULTIVATION AND FERTILIZATION PRACTICES OR EMPLOYMENT OF MEN AND EQUIPMENT?

A There probably is no advantage to be gained in the areas of cultivation fertilization or employment practices because of better information

Q WHAT SPECIFIC FORECAST WOULD BE MOST USEFUL TO MANAGEMENT?

A Specific forecasts of heat unit deviations would be of greatest use since planting schedules are based upon this system Planting subject to other constraints could then be optimized To be most useful heat unit forecasts should extend through a 180-day period although conditions over the first 90 days of the planting season are the most critical in terms of crop return

EXHIBIT II-2 (Continued)

better information will make a substantial contribution to water management throughout the power-producing and using groups Two other points are worth emphasizing in this summary First, the fact that the Columbia Basin is a highly complex management organization with completely interdependent public and private water interests is important in that it points up the general need for better information to support management decisions If it had been determined that the dams of some power producers were wholly interior to the BPA system, this may have indicated less need for total information dissemination This is not the case, however, and better management information is needed by all participants in the system

A second pivotal concept is that information needs will tend to increase during the next decade Taken together with the stated need for better information now, an increased requirement points up the need for a more accurate system that is highly responsive to users

In the private sector, it was found that aluminum production is highly dependent on a continuous, heavy power supply Power stoppages beyond 4 or 5 hours were described as "catastrophic" in terms of financial loss to the affected company As indicated in Exhibit II-2, better information leading to secondary power smoothing will materially assist production planning As it stands now, major aluminum producers in the Northwest are required to gamble by buying "provisional" power that might, as a result of unfavorable circumstances, have to be repaid at great cost

User information needs for irrigation are not as critical, although short-term forecasts will be highly beneficial Visits were made to the Bureau of Reclamation Regional Office in Boise, Idaho, to discuss information applications for irrigation Results of these conversations generally followed those derived from the visit to the Del Monte Company in Portland, Oregon Basically better forecasts of the supply and demand for irrigation water could allow more profitable options to be exercised by irrigation farmers

To investigate the potentialities of extrapolating the analysis of the Northwest to other regions of the country, similar interviews and

discussions were conducted with power operators and managers in California and the Northeast Results again conformed to the patterns established in the Northwest, leading to the conclusion that there is a general need for a better and more responsive information system

It is, of course, not possible to understand the requirements for information on the part of power managers without defining the needs for flood control management The same flows and reservoirs must be managed during the year for both purposes and the Corps of Engineers sets flood control rules that clearly affect the other users of Columbia River. Flood control information requirements clearly revolve around the need to project the total flood season runoff with adequate alerts to peak flows Both BPA and CE must have such information for optimal water management

The Park Service in the Department of Interior furnished similar information on the benefits of steady reservoir levels during tourist season on the Columbia River The Park Service uses a conventional technique for evaluating the benefits of each additional tourist day generated by better management This convention has been generally accepted throughout government agencies for this type of benefit calculation

Discussions were held with appropriate groups concerned with the navigation on the Columbia River Improved information does not seem to be required by ship or barge owners The channel depths are adequately maintained at this time and the use of larger vessels is not now seriously contemplated Sill depths in the locks of the various dams would have to be modified at great expense if deeper channels were proposed Better information aimed at deeper channels probably could not be used effectively with an expensive modification program Current management now maintaining channel depths over the year at the minimal prescribed depths seems to be acceptable for current and projected traffic needs

B User Sensor Model

The purpose of the user sensor model is to relate the optimum set of sensors to the specific observations that would be of primary use to managers in making decisions in light of current or projected management rules and techniques (Please see Appendix A for a detailed technical discussion of pertinent sensor systems)

The elements of the analysis described in the methodological flow diagram in Exhibit I-1 are all essential to the study and the general sequence of elements is logical and useful in starting the analysis As noted above, a simple pass through the flow diagram is not operationally practical and an iterative treatment is essential Tradeoffs, pattern recognition and other techniques were employed as appropriate to overcome apparent obstacles in developing the overall system concept Thus, although the selection of sensors at this stage of the discussion is somewhat out of order, it probably makes the subsequent presentation of the user decision models more understandable to the reader Certainly in presenting the overall system concept it is convenient to describe the satellite and its sensors, then the telecommunications, data processing and interpretation and finally dissemination to users who will incorporate the new information in their present or projected decision model

It proved possible to proceed in a fairly elementary manner toward the selection of the recommended sensor package The basic operational inputs to the user decision models were defined. Often the preferable input could not be measured directly by available sensors It was usually then possible to specify observable measurements for incorporation into earth sensor submodels which, when proven out, would give the inputs necessary for decisionmaking For example, measures of snow area and indications of snow depth can be used with appropriate estimating relationships to project snow volume and water equivalent (see Appendix B)

It seems appropriate to start with state-of-the-art capabilities as the base case in conceptualizing the operational system This base case is referred to in another part of the study as Advanced I. The question then becomes one of finding appropriate system techniques which will permit state-of-the-art sensors to support a system acceptable for decisionmaking The present study indicates that the state-of-the-art detection capabilities relative to false alarm rates and resolution can very likely support an operational system, given the developmental research required in the earth sciences It was not possible in the present study to determine if the success in the earth sciences submodels is likely to be so high that weight and power, for example, can be reduced by backing off from the Advanced I level of sensor capabilities A developmental research program to establish a state-of-the-art system of sensors operable at satellite altitude to prove out the appropriate earth sciences submodels should ensure a successful operational system, given the usual unexpected successes and failures in any R&D program.

1 Principal Satellite Observations Required

The principal satellite observations required by the subbasin model, developed in the section below, can be summarized as follows

- Snow area
- Indicators of snow depth relating to objects of known heights
- Indicators of snow depth by albedo (light reflections) measurements to identify new snow and possibly snow depth (by albedo reduction from protruding rocks, bushes, etc)[1]

[1] A radar which could be developed which could add another dimension might sense snow depth directly by measuring the difference in reflectance from snow of one frequency that penetrates snow and another does not. This is not now state-of-the-art

- Rain and snow rates of precipitation
- Precipitation areas
- Surface temperatures from which precipitation quantity, soil moisture, evapotranspiration conditions and snow melt may be estimated
- Soil moisture
- Surface water areas
- Distinction between open water and ice and condition of vegetation

The organization of these various observations in an overall flow diagram is presented in Exhibit II-3, entitled, "Potential Sensings From Satellite." The interaction of these observations and decision-making will be seen in the models and scenarios presented in subsequent sections

2 Selected Sensors

Willow Run Laboratories furnished PRC with the basic information on the various available sensors These data are presented in Exhibit II-4 and, with the insights obtained from the models and decision rules described below, permit the choice of acceptable sensors. The sensors are broken into two groups (1) Advance I sensors that are within the state-of-the-art for early deployment in the early 1970's given developmental funding, and (2) Advanced II sensors that involve research in greater depth to make them potentially available in the early 1980's.

It will be seen from Exhibit II-4 that the parameters that the laser and passive microwave could measure can be provided directly or indirectly by the Advanced I sensors Advanced I sensors therefore appear to be adequate initially to provide the information necessary for water management This should in no way preclude further research and development of other sensor systems, particularly the passive

microwave and laser altimeter It is not anticipated that firm decisions will be made at this time to fix the exact composition of the sensor package to be flown in a subsequent unmanned satellite

The recommended sensor package for this study includes the MSS, TV and radar The contribution and complementarity of the individual sensors and the package as a whole can be read from Exhibit II-4 Simply stated the MSS with a broad swath width can furnish most of the required observations with modest resolution when cloud cover does not obscure the line of sight If line of sight is not obscured, the high resolution TV sensor can furnish confirmations and accuracies particularly useful in flood management, which in turn permits more profitable power management Radar, in turn, can furnish the necessary observations on precipitation essential for flood management and interreservoir management The inclusion of radar in the sensor package is not intended to supplant either existing or planned ground radar systems In fact, the ground radar system, like the Hydromet telemetering system, can greatly assist a remote sensing system by furnishing complementary and ground truth data It should be emphasized that, although study rules prevented a detailed examination of current and planned systems in other agencies, this research was done with the thoughts in mind that the system being designed would not operate in a vacuum and that the final operational satellite system might well interface with a series of complementary ground systems

Thus, the MSS, TV and radar are the minimal sensor package It will be seen that state-of-the-art accuracies appear to be adequate when incorporated into an integrated model It is not possible to decide at this

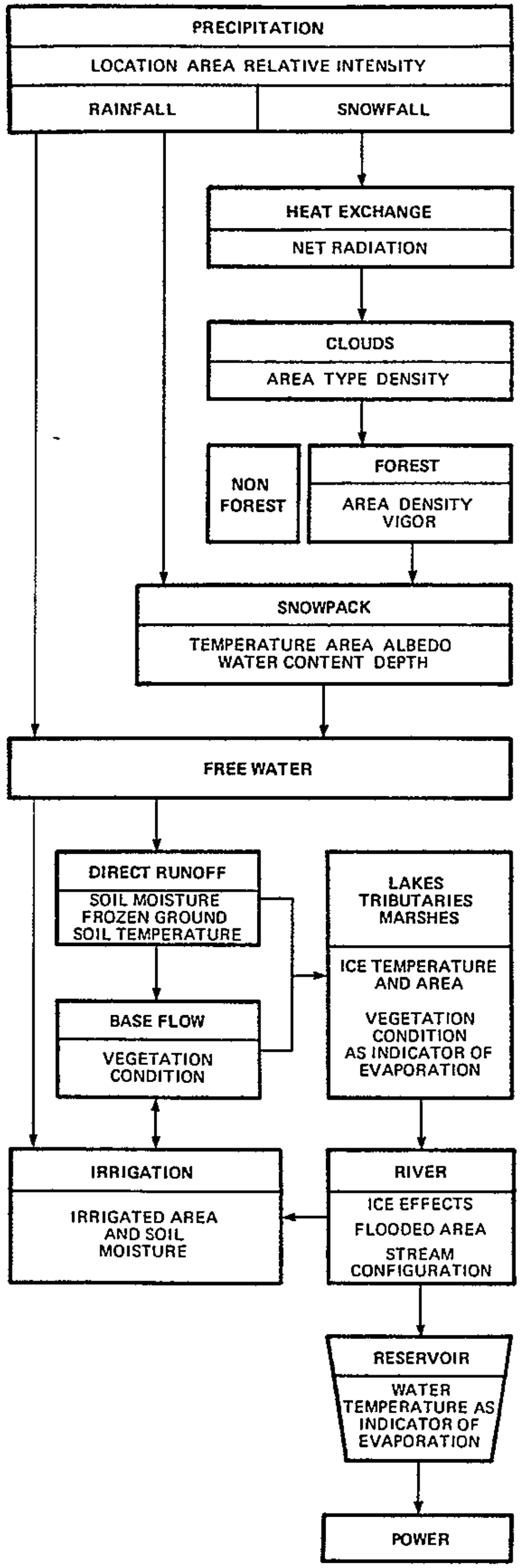

EXHIBIT II-3 POTENTIAL SENSINGS FROM SATELLITE

EXHIBIT II-4 MAJOR HYDROLOGIC PARAMETERS AND SENSOR CAPABILITIES

	Advance I Sensors								Advance II Sensors			
	Multispectral Scanner		TV		Radar		Infrared		Laser		Passive Microwave	
	Linear Resolution (ft)	Parameter Resolution	Linear Resolution (ft)	Parameter Resolution	Linear Resolution (ft)	Parameter Resolution	Linear Resolution (ft)	Parameter Resolution	Linear Resolution (ft)	Parameter Resolution	Linear Resolution (ft)	Parameter Resolution
Snow area	1 800	1 800 ft	100_s	100_s ft	1 $800_{r\ s}$	1 800 $ft_{r\ s}$	200	200 ft		-	-	-
Indicators of snow depth relative to objects of known heights	-	-	100_s	100_s ft	-	-	-	-	Potential capability	Potential capability		-
Indicators of snow depth by albedo (light reflectance) measurements to identify new snow and possibly snow depth (by albedo reduction from pro truding rocks bushes etc)	200	± 3 5% reflectance	Potential capability	-	-	-		-	-	-		-
Rain and snow rates of precipitation	-	-	-	-	1 $800_{r\ s}$	$5_{r\ s}$ inches		-		-	7 000	Up to 2 5%
Precipitation areas	5 $000_{r\ s}$	5 $000_{r\ s}$	5 000_s	5 000_s	5 $000_{r\ s}$	5 000 $ft_{r\ s}$	-	-	-	-		-
Surface temperatures from which precipitation quantity soil moisture evapotranspi ration conditions and snow melt are to be estimated	2 400	+1° F			-	-	-	-	-	-	-	-
Soil moisture	1 800	± 1 point	-	-	50	Potential capability	-		-	-	7 000	Indication of moisture in top 1 to 2"
Surface water areas	$200_{r\ s}$	200 $ft_{r\ s}$	100	100 ft	$200_{r\ s}$	200 $ft_{r\ s}$	200	200 ft	-	-	-	
Distinctions between open water and ice and condition of vegetation	-			-	1 $500_{r\ s}$	5 $ft_{r\ s}$		-	-	-		-

s - Indicates ability to sense snow
r s - Indicates ability to sense rain or snow

time that weight, power, and other factors can be reduced by using less than state-of-the-art sensor accuracies. It will be seen below that currently practical sensors, if proven effective at satellite altitudes, introduce only very small errors into the system in most real cases

The several paragraphs below define in more detail the attributes and capabilities of the recommended sensor package for the water management case

a Multispectral Scanner

The multispectral scanner includes both a capability for identification by spectral analysis in the visible and near infrared and a capability for mapping temperatures of ground surfaces, water, ice, snow, or foliage Since automatic methods of data processing can be used, the multispectral scanner readily lends itself to handling data for large areas at frequent repetition rates Within the operational period of the satellite-assisted system, automated systems can be developed so that there will be little or no need for human intervention in the processing of the data

Measurement of snow area would be accomplished by identifying snow cover against such backgrounds as soil, rocks, and vegetation and summing the total area by an area-counting device One problem which must be satisfactorily solved in any type of automatic method for snow identification is that of distinguishing between snow and cloud cover Spectral data on snow and clouds available at the present time are insufficient for analysis of spectral discrimination means Other possibilities for discrimination would include pattern recognition of differences between cloud shapes and snow patterns or discrimination on the basis of altitude differences using some type of ranging device or temperature differences by means of the infrared channel of the scanner Further study will be required to determine which of these possibilities would be best suited to the solution of the problem

By distinguishing snow from clouds, the scanner provides a measure of instantaneous cloud cover This would allow corrections to be introduced into the automatic multispectral processing operations to account for variations in illumination conditions The cloud cover information would also be of use to the hydrologist in heat budget studies

Discrimination of wet soil from dry soil would provide a method of estimating soil moisture or detecting recent rainfall

The infrared channel of the multispectral scanner could provide a reasonably precise measure of snow emittance, which would be useful in heat budget calculations and would also give some indication of the snow characteristics Lowered reflectances in the visible region tend to indicate melting or aging of the snow surface, thus providing some indication of history and current condition of the snow

The thermal infrared channel of the multispectral scanner provides for the measurement of temperatures of rocks, soil, water, snow, and vegetation Measurement of foliage temperatures may also be a good indicator of air temperatures close to the earth's surface Accurate calibration techniques are required to correct for instrument errors and atmospheric effects, but analysis of this problem, presented in another section, indicates that absolute accuracies of 2 or $3^{\circ}K$ in measurement of snow surface temperatures should be possible

There is adequate signal-to-noise ratio and scanning time for the MSS to scan out to useful swath limits Scattering and attenuation of infrared radiation (IR) increases rapidly with increasing path length through the atmosphere Off-zenith angles at the earth of 20° for IR and 60° for visible light are considered reasonable limits Also, chromatic aberration of IR lenses becomes important at wide angles

Accordingly, higher altitudes are preferred because the swath width grows essentially linearly with altitude, while the number of passes per day goes down very slightly. Two examples are given below

Altitude (n mi)	20^{o} Swath Width (n mi)
300	210
500	320

b. Television Systems

The use of television systems for the collection and analysis of hydrologic data provides a capability similar in nature to that of aerial photography, but having the advantages of large-scale repeated area coverage, and rapid and comprehensive data availability In addition to human photointerpretation of the incoming imagery, it would be possible to develop automatic methods of data processing (e g , for measurement of snow area), although these methods would generally be less accurate and flexible than those which have been developed for the multispectral scanner

Specific uses of television imagery will depend on the resolution and number of spectral channels available Black-and-white low resolution imagery (of the order of 500 ft) would probably be adequate for indicating the lateral extent of snow cover and measuring its area Resolution in the range of 50 to 100 feet would provide a more definitive indication of snow cover, with less chance for ambiguity or misinterpretation Beginning at these resolutions, and improving at resolutions of 10 feet, the imagery would not only indicate the distribution and amount of snow cover, but would give indirect information on snow depth based on the extent to which the snow covers the soil and vegetation surfaces

Depending on resolution and number of channels, television imagery could also be used to observe such features as the type and condition of snow, extent and distribution of surface water of flood expanse, and condition of vegetation (as an indirect indicator of surface or subsurface water). At high resolutions, some indication of the relative magnitude of discharge might be obtained by measuring stream width, which is related to river stage Certain flood plain locations along each stream with shallow banks would provide the most sensitive indication of river stage

Wherever ground surfaces are covered by trees, sensors operating in the visible and infrared wavelengths will not penetrate the foliage, but will be able to observe ground surfaces through openings in the canopy and in forest clearings This can be done most successfully when the direction of viewing is near the vertical Snow cover resting on the canopy itself will give a useful indication of additions to the snow cover or of the condition of old snow

c <u>Radar Systems</u>

Because the security classification of certain technical aspects of radar is above the level of this report, no detailed technical discussion of the radar systems can be included Radar contributes to the sensing of important hydrologic parameters, however, and a description of the general characteristics of radar which are relevant for the hydrologic sensing system is appropriate for this report

Radar has been found useful for detecting or measuring precipitation in the atmosphere Operational weather radar systems generally operate at 3 to 10 cm wavelengths At these wavelengths, radar is able to detect the presence of rain in the atmosphere, but is less sensitive to the water content of non-precipitating clouds At shorter wavelengths of 1 cm and less, the reflected signal and attenuation of the transmitted energy by both rain and clouds increase substantially

Snowfall can also be detected by radar Signal reflection from falling snow has roughly the same strength as for rain with the same precipitation rate in terms of mm/hour of liquid water

In spite of the increased attenuation at wavelengths of 1 cm or less, they appear to offer the best performance for detecting precipitation from orbital altitudes, since rain and snow have greater radar cross-section at these wavelengths and will therefore produce a stronger signal return for a given pulse power Since the direction of viewing from the satellite is nearly vertical, the total round trip distance traveled by the radar pulse through clouds and rain is usually limited to less than a mile Hence attenuation effects are not likely to have a serious effect on the

radar signal return A wavelength of 1 cm, which shows some attenuation from clouds, can therefore be considered suitable for this application

An additional advantage of the shorter wavelength is that the antenna beamwidth can be decreased for a given size of antenna, resulting in smaller resolution element sizes

As an indication of the capability of a precipitation detection radar, a study was made of a radar operating at 1 cm wavelength. The radar would use a 4 ft x 4 ft phased-array antenna, capable of scanning laterally over a $\pm$ 50 degree angle. The radar would send out 1-micro-second pulses at a peak power of 15 kw, and a pulse repetition frequency of 200 per second. This corresponds to an average output power of 3 watts At an altitude of 300 n mi , the area illuminated by the radar beam at the edge of the swath would be 4 7 by 4 7 n mi If this resolution element were completely filled with rain falling at a rate of 2 5 mm/hour, corresponding to a light to moderate rainfall, the signal return power received by the radar would be 1 4×10^{-11} watts, about 10 times above its minimum detectable signal At a pulse repetition frequency of 200 per second, the radar would be able to search over a swath width of 720 n mi If the volume of rain did not completely fill the area illuminated by the radar beam, it could still be detected if the rate of precipitation were greater than the 2 5 mm per hour specified above Greater sensitivity could also be achieved by increasing the average power of the radar

In using an orbiting radar system to detect the areal distribution of rainfall, it will be necessary to avoid confusion between ground clutter and signal return from the precipitation itself For pulses transmitted in a nearly vertical direction, the earliest return representing ground clutter will tend to come from the highest point in the terrain illuminated by the beam By using range gating methods, precipitation which occupies the volume above this highest point can be observed, but clutter will interfere with the signal at lower altitudes At substantial angles from the nadir, ground clutter could interfere with detection of precipitation if the bottom edge of the main beam or its sidelobes contact the

ground before the main beam reaches the atmospheric volume to be observed To minimize this effect, the beamwidth of the radar in the vertical plane normal to the satellite velocity should be kept to a minimum This requires an antenna whose aperture normal to the satellite velocity is made as great as possible The design should also aim to reduce side-lobes over the angular region which would cause the most serious trouble.

Radar systems have been found to be capable of measuring rainfall rate with fair accuracy under carefully controlled conditions However, it is not believed that quantitative measurements will be possible from an orbiting radar system such as that discussed in this report Satellite coverage of the area will not be continuous, but will consist of repeated sampling at regular intervals determined by the number and spacing of the satellites Also, ground clutter would prevent the detection of rainfall in atmospheric volumes shielded by the clutter Establishing the necessary calibration procedures for accurate measurement of precipitation by radar would also be a sizable problem, but could probably be accomplished if sufficient research is devoted to the problem It is possible, also, that by the use of more than one wavelength, with different capacity for penetrating rain, some ability to distinguish various levels of rain intensity could be achieved In spite of the limitations mentioned above, the system would be capable of providing frequently repeated coverage of large areas to observe the areal distribution of rainfall and to provide some indication of its intensity.

The radar system described above, using a 1 cm wavelength and a 4 ft phased array antenna, could be placed in orbit by 1973 As indicated previously, the ability to detect rain would be restricted, by the attainable resolution, to sizable rain cells and appreciable rates of precipitation Interpretation of the data would be complicated to some extent in attempting to observe rain at large angles from the nadir, because of poorer resolution and the possibility of ground clutter, but sizable swath widths should still be possible

By 1980, a system with substantially improved capabilities should be possible. Experience with the 1973 system and additional

research in radar meteorology will make possible improved methods of signal interpretation The use of additional frequencies and the analysis of return echos received at different polarizations would permit better discrimination of ground clutter and of various forms of precipitation, and more quantitative estimates of precipitation rates Also, increases in available sizes of scanning antennas would improve resolution capabilities Although the observation of a specific area would still be intermittent, it is possible that the data collected by the radar and other sensors could be used to estimate rainfall occurring between observations

Although the preceding discussion of radar has dealt mainly with the detection of precipitation, it is equally important that the radar system onboard the satellite be capable of detecting surface phenomena through the clouds The problem of selecting the proper frequency or frequencies to perform this function is more complicated than the selection of weather detection frequencies and in fact, involves a series of capabilities tradeoffs

Off-the-shelf equipment and/or well developed technology exists for designing and constructing a focused-synthetic-aperture radar, the only type capable of reasonably fine resolution for satellite borne operation Once the satellite flight parameters are known and the required resolution and operating frequency of the radar are selected, the remaining parameters of an optimal system are essentially determined by the ambiguity function and recorder and processor limitation Each of these points will be discussed separately

Just as with optical imagery, higher resolution radar imagery reveals greater details of the surveillance area at an increased confidence level but requires (and warrants) more careful scrutinization by trained personnel to extract the output data Although resolution can be arbitrarily selected, high resolution can be achieved only at increased cost or significant tradeoffs of the other parameters Therefore, the lowest resolution acceptable for the contemplated use of the imagery should be specified For agricultural observations, where farm fields are generally 600 feet or more on a side, 50 ft resolution appears to be satisfactory Imagery with such coarse resolution does not display crop

structural details, such as the rows of corn, but should be adequate for measuring acreage, agricultural activity, and crop backscatter It should also be adequate for hydrologic studies since terrain, glacial and drainage features tend to be of this same size or larger

The sensor capabilities for providing the necessary elements of forecasts and the contribution of forecasts to management decisions and ultimate benefits are summarized in the system dependency matrix for water management (Exhibit II-5) The various sensors are shown on the lower right corner of the matrix [1] Each sensor makes a contribution to the physical measurements such as streamflow, rainfall, snow area-high level, snow area-low level, etc The physical measurements are used in making forecasts such as seasonal snowmelt runoff, seasonal rainfall runoff, etc The contribution of each measurement to the forecast is ranked by a grading system of 1 through 4 The number 1 means that the physical measurement is sufficient to make the forecast possible The number 4 means that the physical measurement makes no contribution to the forecast The number 2 signifies a major contribution and number 3 some contribution In several instances, two numbers appear in a cell meaning that the value of the physical measurement to the forecast, for example, lies between the two values All the physical measurements making a contribution will be used by the system in making the forecast The value of each forecast element in the management decision/benefit areas is similarly valued by placing an appropriate number, 1 through 4, in each cell

A more detailed treatment of hydrologic variables and data collection techniques is shown in the Appendix B

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[1] The sensor matrix includes color TV, a 7-channel multispectral scanner, radar, microwave radiometer, and an infrared scanner However, only the TV, multispectral scanner, and radar were selected for use in the model

EXHIBIT II-5 REGIONAL WATER MANAGEMENT - EARLY OPERATIONAL SYSTEM

MANAGEMENT/BENEFIT AREAS	Seasonal Snowmelt Runoff	Seasonal Rainfall Runoff	Streamflow Surface	Streamflow Groundwater	Streamflow Maxima	Streamflow Minima	Load Variation (Power)
Drawdown Refill Strategy	2	2	2	3	3	2	2
Inter-Reservoir Coordination	3	3	2	3	3	3	2
Head Efficiencies and Hedge	3	3	2	3	2	2	2
Flood Control	2	2	3	3	2	3	4
Irrigation	2	2	3	2	3	3	4

(FORECAST AND/OR) ELEMENTS OF MANAGEMENT DECISIONS

Seasonal Snowmelt Runoff	Seasonal Rainfall Runoff	Streamflow Surface	Streamflow Groundwater	Streamflow Maxima	Streamflow Minima	Load Variation (Power)	MEASUREMENTS	SENSORS: TV	MSS	Radar	MWR	IR Scanner
3	3	2	2	2	2	4	Streamflow (Antecedent)	3 (A)	3 (A)	3 (A)		
4	2	2	2	2	3	4	Rainfall	3	3/4 (L)	2	3 (T)	3
2	4	3	2	3	3	4	Snow Area - High Level	2	2/3 (N)	2/3	3	3
3	4	3	3	2	3	4	Snow Area - Low Level					
2	4	3	2	3	3	4	Snow Water Equivalent - High	2/3 (A)	2/3 (A)	2/3	3 (S)	3
3	4	3	3	2	3	4	Snow Water Equivalent - Low					
3	4	3	3	3	3	4	Snow Temperature - High		2		3 (S)	2
4	4	3	3	3	3	4	Snow Temperature - Low					
3	4	3	3	3	3	4	Snow Albedo - High	2/3	2 (S)			
4	4	4	4	3	3	4	Snow Albedo Low					
3	3	3	3	3	3	2	Air Temperature		2 (T)		2 (T)	2 (T)
3	3	3	3	3	3	4	Ground Temperature		2 (T)		2/3 (T)	2 (T)
3	2	2	2	2	3	4	Soil Moisture	2/3	3 (L)		2 (S)	2/3 (T)
2	2	2	3	3	3	4	Evapotranspiration		3 (U)		2/3 (U)	2/3 (U)
4	3	4	4	4	4	2	Cloud Cover	1/2	1/2 (T)			1/2 (U)

LEGEND

1 Sufficient
2 Major Contribution
3 Contribution
4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT II-5 (Continued)

A	Too low a spatial resolution
B	Can detect but not quantify
C	On the basis of area extent only
D	On the basis of low resolution shape information
E	Insufficient resolution for identification by shape and insufficient spectral information
F	Would be excellent if sufficient spatial resolution were possible
G	On the premise of spectral recognition
H	High frequency observation required
I	After fall of rain
J	During fall of rain at time of passage
K	Depending on time of diurnal cycle, transpiration controls plant temperature
L	Could detect wet versus dry soil
M	Could detect heavy rain
N	Obscured by clouds
O	Limited swath width
P	Thermal infrared channel
Q	Qualitative indication
R	Inference from cloud cover
S	Better resolution offers improvement
T	Better resolution would improve interpretability or discriminability
U	Improved discrimination, technique, accuracy, or interpretability

C Hydrological Models

The problem of modelizing in the water management case involves two major parts In the first part attention must be directed to techniques of incorporating sensor observations into an integrated model capable of forecasting stream flows at the bottom of the subbasin as the water enters the main stem of the river The second part involves the development of a river management technique for estimating the benefits of improved data To accomplish this latter, a very simplified river model is developed In subsequent sections the benefits to hydroelectric power generation, flood control, irrigation, and recreation are calculated

1 Subbasin Forecasting Model

This section describes the Pacific Northwest, the Columbia River Basin, and the three selected subbasins chosen for more detailed study The general hydrological, meteorological, and geological conditions in the area are defined The current level of instrumentation is indicated and the abilities of sensors to function in the face of serious cloud cover are analyzed A major problem involves the modeling of a subbasin essentially aimed at describing the routing times and disposition of a given impulse of water into the subbasin An impulse can be a rain or snow storm, or a certain volume of snow pack melt The subbasin is modeled in terms of the hydrograph at the bottom of the subbasin This modeling was undertaken to study this phenomenon and, in particular, to ascribe the sensitivity of the final results to the major components This, in turn, has some implications as to which sensor observations are most critical.

The modeling completed in the study does perform this function, however, a more complete modeling, capable of projecting stream flows based on sensor observations, and the probable errors at the gage at the bottom of the subbasin could not be fully implemented Two things are lacking which can be obtained eventually through developmental research First, the precise identification capabilities, resolutions, etc ,

of the sensors can only be projected at this time Second, earth science submodels required to convert, for example, snow area and depth indicators into snow volume and water equivalent are not now available. Lacking these inputs, a detailed scenario showing the dynamic relationships of observations and their impact on flow forecasting has been developed This scenario shows that, with the developmental research defined above, a Moving Forecast Scale for the gage at the bottom of the subbasin can be developed The scenario further indicates that the error envelope around the Moving Forecast Scale is likely to be within acceptable limits for decisionmakers

a Objectives

The subbasin model simulates the water movement cycle from the time water enters the drainage area in the form of rain or snow until it leaves the drainage basin, either by evapotranspiration or streamflow past a gaging point. The subbasin model is designed to

- Show the interaction of hydrological and meteorological factors in producing stream flows
- Show the role of observations in the forecasting process
- Identify and measure the sensitivity of outflow to factors that a satellite might observe, both hydrological and meteorological variables and substantially fixed basin features such as area and geology
- Make it possible to set up, in correct order of priority, a list of parameters to be sensed and thus make it possible to set specifications for satellite capabilities

b Analysis

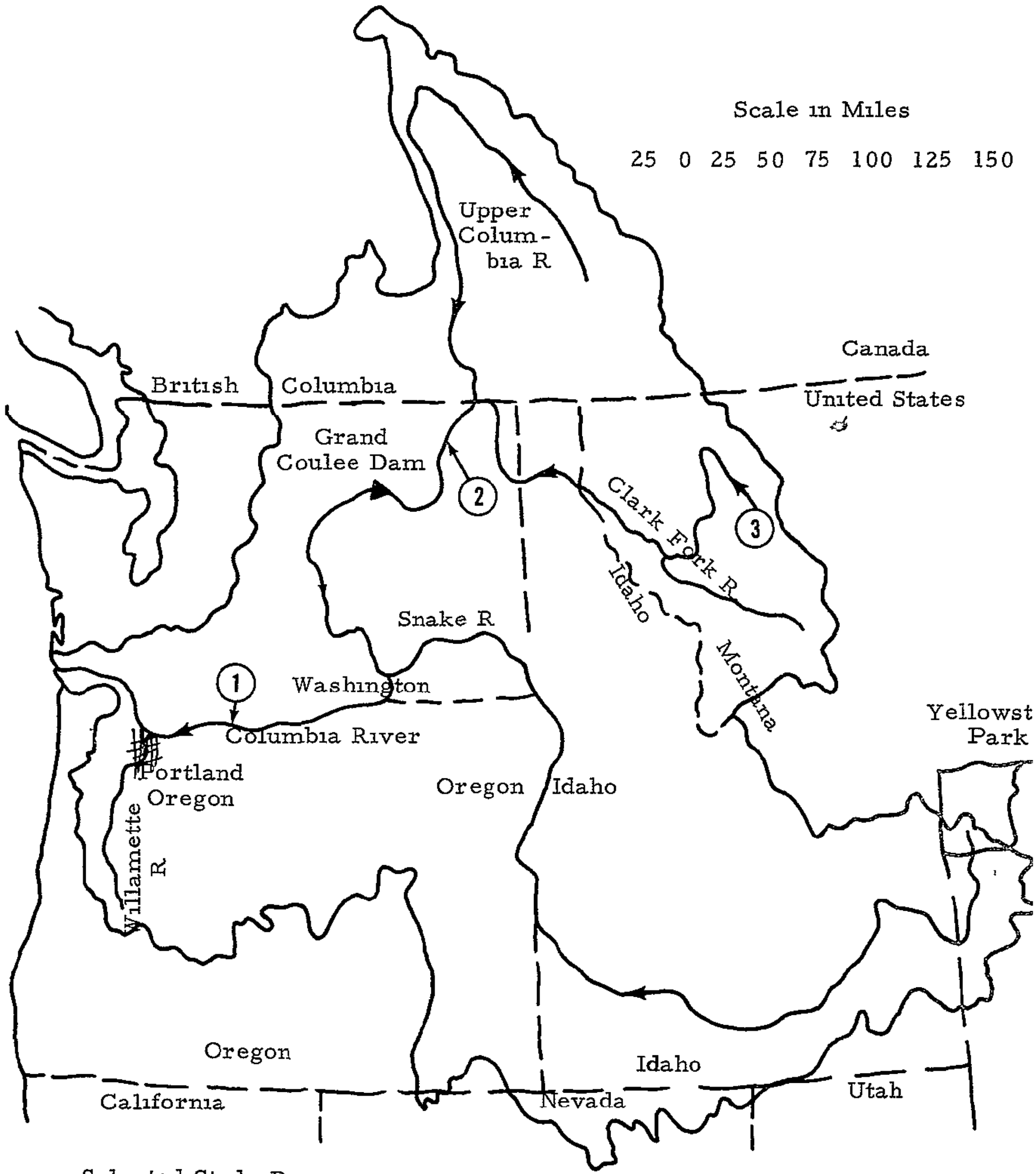
The modeling problem is to isolate and quantify the importance of various potential hydrological phenomena to be used to improve runoff forecasting The first step is to identify observable factors whose correct identification and measurement are particularly important in the forecasting process Of these, the ones most likely to be observed are surface temperature, snow-covered areas, vegetation,

soil moisture, areas of free water, ongoing precipitation (and areas of recent precipitation), and snow water equivalent. The precision with which these phenomena can be measured varies In some areas, reliable measurements are not within current sensor capabilities Most are, however, either by direct measurement or by inference, and there is reason to believe that this capability will improve as sensor development progresses

The Columbia River system was selected as the testing ground for the study because of the relatively extensive use of instrumentation in the system, because of the availability and abundance of historical data, and because the area is a major site of hydroelectric power production The complexity of its environment also permits the greatest variety of satellite capabilities to be exercised within the basin Specific subbasins within the basin were chosen for intensive analysis in order to limit the number of factor interactions to be considered

Exhibit II-6 is a display of the overall drainage system covering about 260,000 square miles. For forecasting and water management purposes, this area is divided into approximately 52 basins. Three subbasins of about 1,000 square miles each are indicated in Exhibit II-6 (1) Klickitat, (2) Colville, and (3) South Fork of the Flathead River. (See Appendix B for detailed basin descriptions.) These areas were chosen for closer attention because they represent a wide range of geological and meteorological environments

Exhibit II-7 points up the forecasting problem The curve shows the variations in total annual streamflow measured at the Grand Coulee Dam on the Columbia River These variations are obviously diverse, both in direction and degree. Since the quantity and timing of runoff are the chief constraints on the utilization of water flow, the managers of the river system make planning decisions based upon their best forecasts of what runoff will be It should be noted that Exhibit II-7 shows only the variations in yearly totals Graphs of daily flows indicate even more clearly the forecasting problems faced by managers of the river system



Selected Study Basins

(1) Klickitat River Basin

(2) Colville River Basin

(3) South Fork Flathead River Basin (Above Hungry Horse Dam)

EXHIBIT II-6 COLUMBIA RIVER BASIN

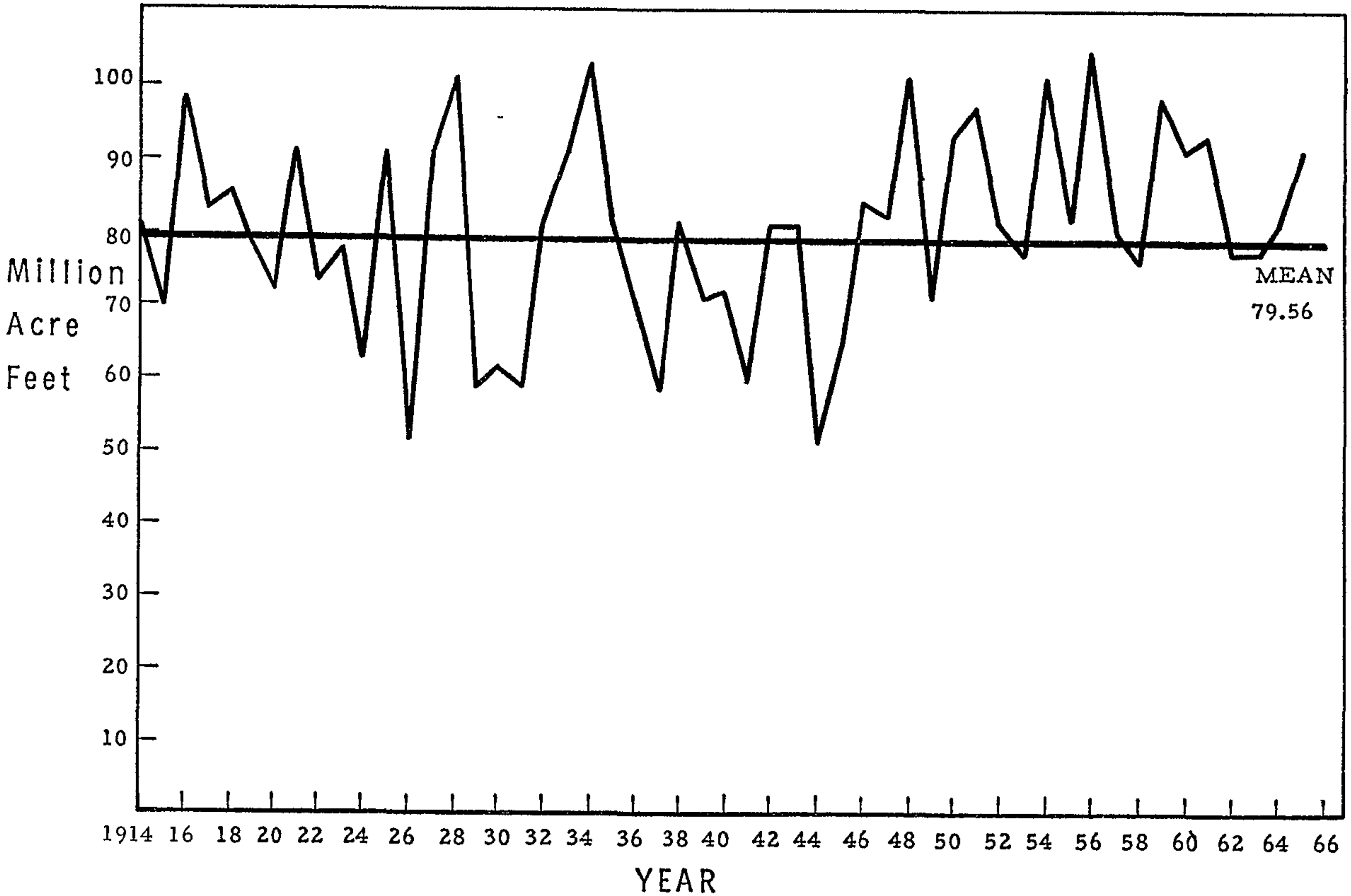


EXHIBIT II-7 ANNUAL RUN-OFF AT GRAND COULEE DAM

Approximate seasons for rain and snow for major sectors of the river system are shown in Exhibit II-8 The bars do not show relative magnitudes by month, but merely type of precipitation There are wide variations in total amounts over the area covered by the mountains More precipitation occurs in the higher elevations where moist air is cooled by being driven to higher altitudes This dumping of precipitation on the windward slopes reduces precipitation on leeward slopes and plains

Exhibit II-9 gives an idea of the variation in total precipitation and estimates of the amount of water returning directly to the air via evaporation from the soil and vegetation and transpiration

c <u>Flow Variability and Forecasting Factors</u>

Exhibit II-10 shows river flow and meteorological data over one year, 1959-1960, in the Flathead subbasin In some respects, the whole river system and forecasting problem are here in microcosm, and the subbasin is one of many building blocks in the overall Columbia system

At the bottom of Exhibit II-10, the solid line is the subbasin hydrograph, a record of subbasin outflow rate, which is the subject of forecasting The dashed line, sometimes above and sometimes below the hydrograph, is the depth of snow on the ground Associated with it, in the boxes, are average periodic snow course measurements These measurements are made, at the intervals shown, on a standard set of snow courses during the winter and spring In the middle of the exhibit appears the daily range of temperature, again an average of measurements at a standard set of locations At the very top of the exhibit appears daily precipitation, again an average of gage readings Swings in snow depth, temperature, and precipitation are all contributors to the variation in the hydrograph

In examining these graphs, it is easy to interpret readings as indeed typical of the subbasin, that is, sufficiently representative of what is occurring to "explain" the hydrograph That the explanation is intricate is indicated by comparison of the data for November 1959 with that

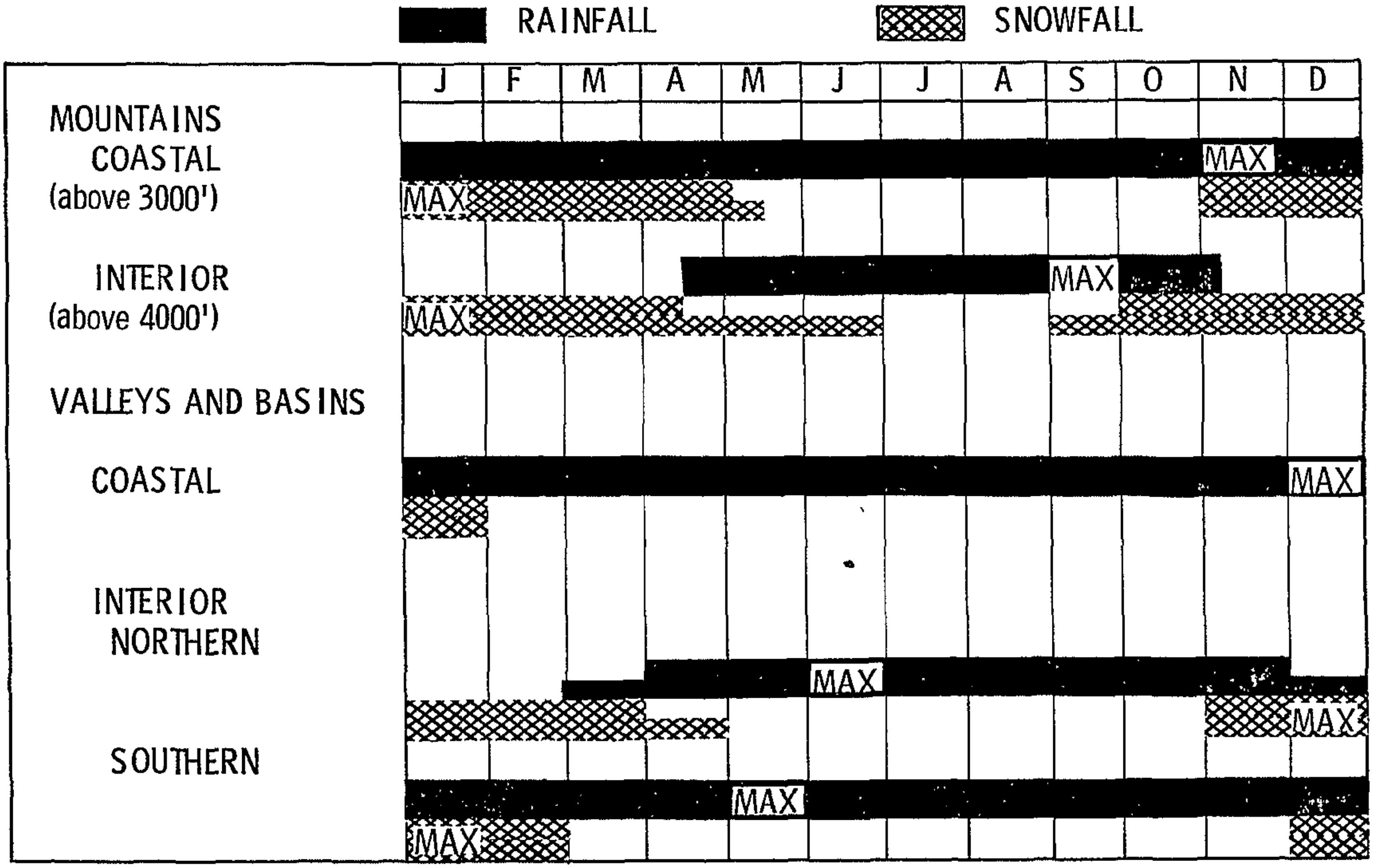


EXHIBIT II-8 COLUMBIA RIVER BASIN MONTHLY PRECIPITATION TYPES

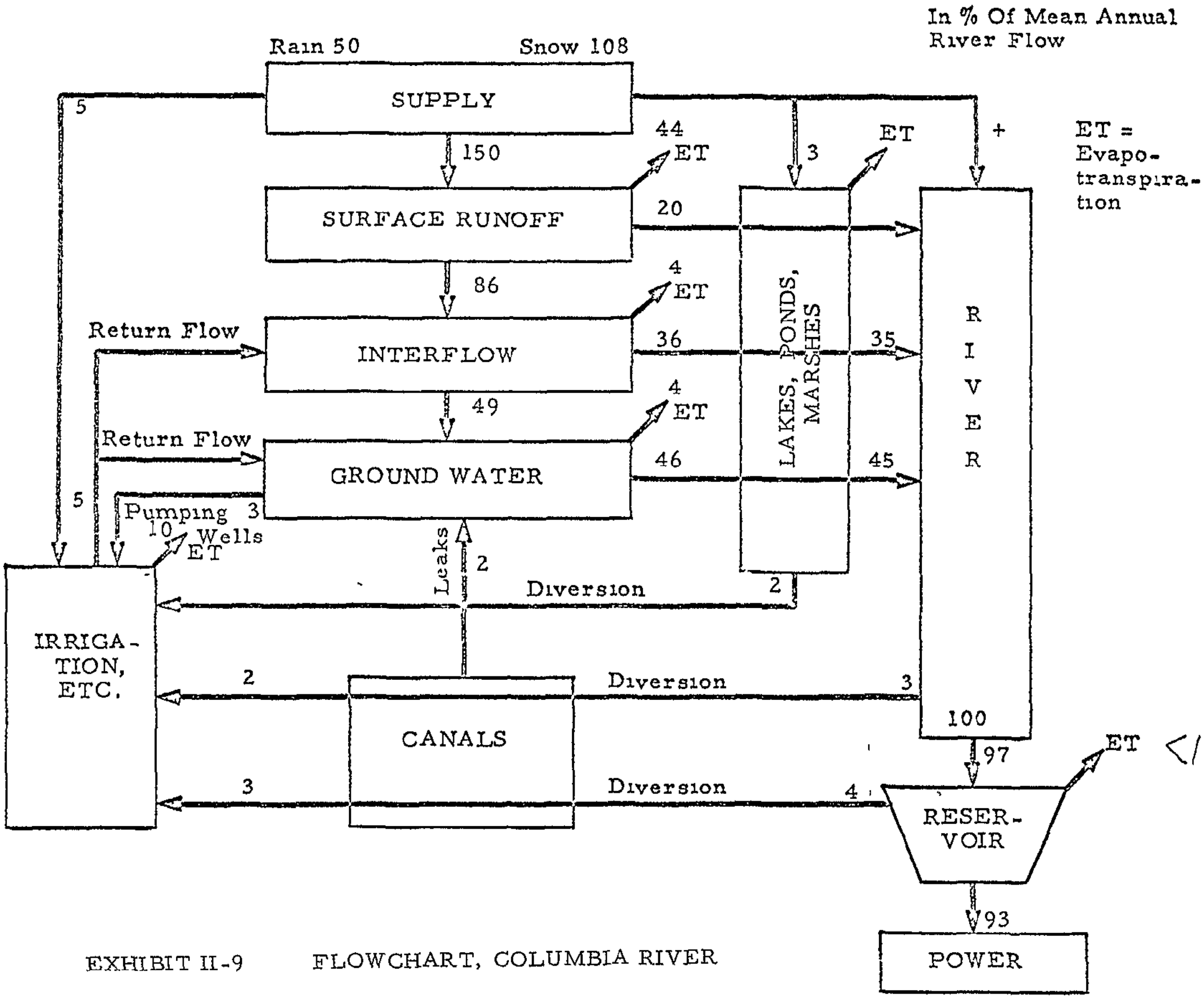


EXHIBIT II-9 FLOWCHART, COLUMBIA RIVER

for June 1960 November precipitation greatly exceeds that in June In both months, temperatures are largely above freezing, so that in both cases precipitation probably was for the most part rain, not snow Yet June flows, even though fed, apparently, by much less precipitation, are much higher and more erratic than those in November

There is an important hydrologic explanation of this anomaly June rain may have fallen on snow and thus run off almost directly to appear as stream flow November rain, falling on bare ground, might have been held by the soil This explanation may indeed be valid, but its worth is not illuminated by the data shown To forecast water runoff correctly, data are needed on where the rain fell, whether the ground was snow-covered or not, and on temperatures in the area

A second reason for the unexplained difference in runoff between June and November is the small sample character of the data Precipitation gages and thermometers, while well-placed to yield representative measurements on the average, can yield unrepresentative averages some of the time--and for a long period if weather is atypical Again, data on the location and timing of precipitation and local temperatures are needed to disclose the extent of sampling and to avoid erroneous forecasts The present modest instrumentation in three subbasins within the Columbia River System is shown in Exhibit II-11

The greatest strength of the satellite-assisted system lies in the ability of the satellite to produce area rather than point data Thus, "typical" graphs of precipitation, temperature and snow cover can be replaced by meaningful and accurate representations of complete subbasins In addition, the variety of sensors available for satellite application make possible the acquisition of new kinds of data

Just below the precipitation graph at the top of Exhibit II-10 are marked off days on which cloud cover would have been negligible, indicated by a vertical line, and days on which useful visibility from the satellite, through light cloud cover, would have been possible, marked by an X Just as weather can block access to meteorological stations, it can block some satellite sensors from the ground A detailed discussion of cloud cover is given in Appendix B Exhibit II-12 shows the extent to which cloud cover in a particularly cloudy year could

FOLDOUT FRAME 1

FOLDOUT FRAME 2

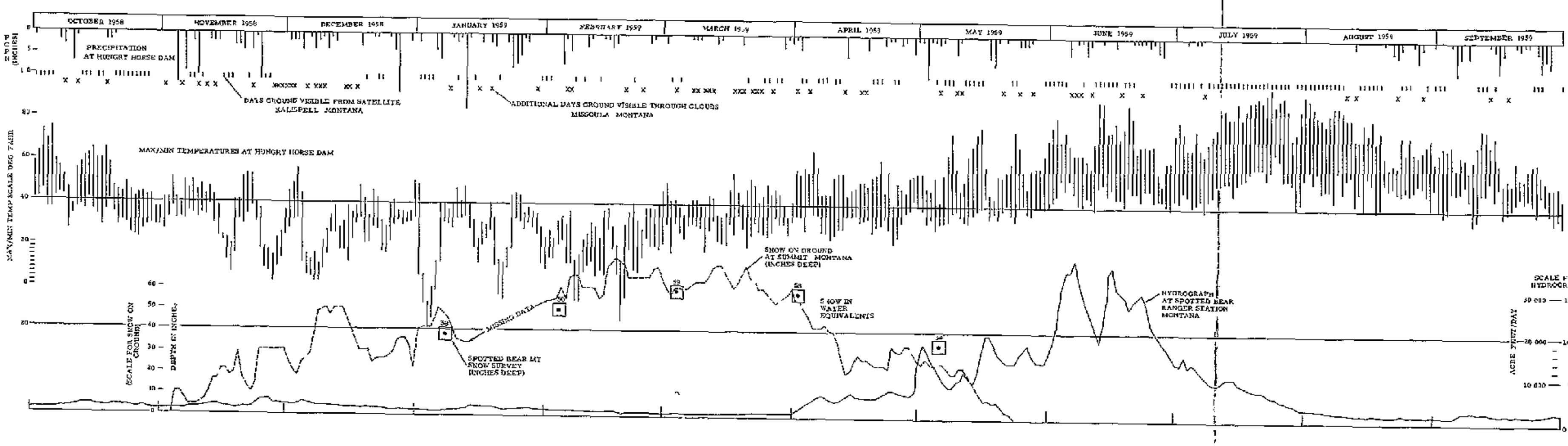


EXHIBIT II-10 HYDROLOGIC/ METEOROLOGIC DATA - SOUTH FORK OF THE FLATHEAD RIVER (October 1958 through September 1959)

Measurement	Hungry Horse Inflow 960 mi^2 drainage (South Fork of Flathead River)	Grand Coulee Colville R B 1000 mi^2	Bonneville Reach Klickitat R B 1300 mi^2
Recording River Gages	1	6	5
Snow Survey Courses	4	4	3
Non-recording precipitation and temperature stations	2	2	3
Non-recording precipitation stations	1	1	1
Non-recording precipitation storage stations	3	0	0
Complete meteorological station	0	1	0
Lake gages	0	1	0
Recording precipitation stations	0	0	1
Recording and non-recording precipitation and temperature stations	0	0	1

EXHIBIT II-11 PRESENT INSTRUMENTATION IN SELECTED SUBBASINS

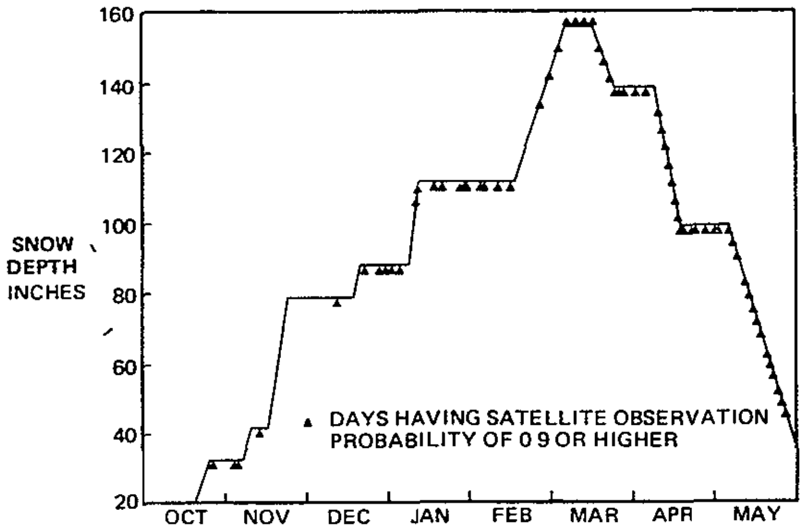


EXHIBIT II-12 SNOW PACK OBSERVATION POTENTIAL, DEGRADED BY CLOUD COVER

block satellite observation of the snow pack The example was taken from weather records in Northwest Montana in the winter of 1955-1956, representing a bad station in a bad year As the exhibits show, weather does not block visibility for long At each inventory level 2 to 12 observations can be obtained under very severe weather conditions From these observations extrapolations can be made from precipitation observations The problem of extrapolation from aging data is not new, in a sense, it is the forecasting problem But it has to be explicitly modelled, and take into account the wealth of new data that the satellite can deliver

Exhibit II-10 shows one year's data, of a kind that extends over many years Also available, of course, are extensive maps of geology, land use, and the character of vegetation by subbasins for an in-depth analysis of hydrological models

Hydrologic modelling emphasizes the concepts suggested by Exhibit II-8 and the particular basin characteristics Verification of the models will involve an exploration of the kind of contradictions discussed previously and a tentative assignment of causes, supported by observations in other years.

Basin characteristics, in existing hydrologic models, describe how the basin transforms precipitation and temperature inputs into a flow output The transformation is not simple, but on the contrary is an exceedingly complex process For example, a large part of the water input to the basin never appears as streamflow This fact is complicated by the necessity to determine the division of input among surface, subsurface, and base flows

The basic model, useful in water management, is shown on Exhibit II-13 It can be seen that satelliteborne sensors will help measure rainfall, snow cover, snow melt and water flows Together with meteorological inputs, they will improve flow forecasting for water management

The subbasin model described below simulates water acquisition and movement through the subbasin (i e , the surface/subsurface/base water flow model of Exhibit II-11)

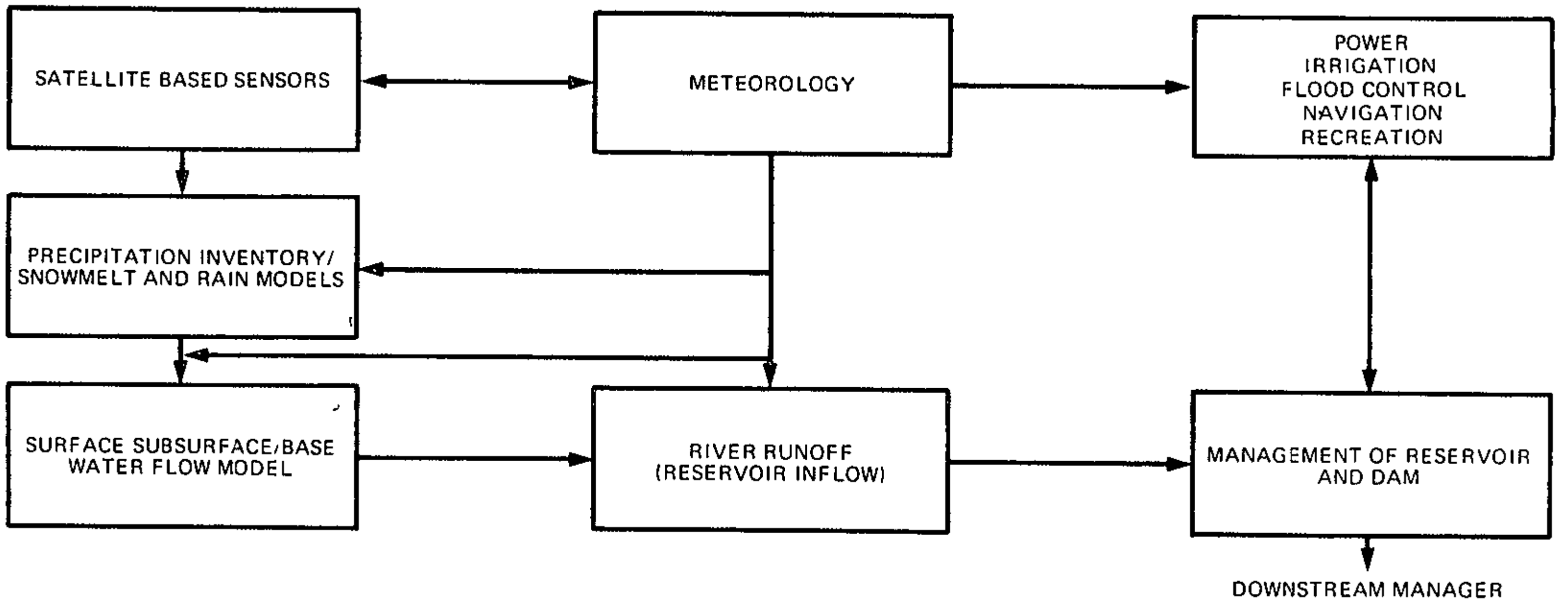


EXHIBIT II-13 SIMPLIFIED HYDROLOGY MODEL

d Methodology for Developing the Subbasin Model

It has now become apparent that the routing and timing of water impulses into a subbasin represent a complicated process PRC has developed a simple simulation model to account for this process and to estimate the hydrograph that would be traced at the gage at the bottom of the subbasin This model was developed to study the routing and timing problems and, in particular, to analyze the sensitivity of the results to the various hydrological factors involved.

A complete model capable of developing the forecasted hydrograph over considerable periods of time and its probable error could not be accomplished The earth science submodels required are not now available. As noted above, it is not possible to estimate and attach probable errors to water equivalent values for various snow fields. Volumes of melt from snow fields under different conditions are also inadequately defined, as well as the potentiality of calibrating marshes, lakes, and flood plains to estimate volumes of flow Lacking this information, however, it is possible to obtain considerable insight into the problem and the probable accuracies of forecasts by developing a typical scenario of the developments during a given season in a given subbasin Such a scenario is described in detail and it is apparent that through pattern recognition techniques, repeated observations, and other estimating techniques, it is reasonable to project very high, overall accuracies for the integrated system

Exhibit II-14 outlines the major features of the subbasin model [1] Temperature assignments are used to determine whether a given precipitation event was rain or snow It is also used to determine the amount of melt release when snow is present A portion of each rain and snowfall will be interpreted by trees and grass and returned to the air when conditions permit The rest reaches the ground

A snow inventory account is kept and used to estimate melt releases The inventory is also used to determine the fraction of the basin

[1] A mathematical explanation of the subbasin model and the computer program for operation of the model are furnished in Appendix B.

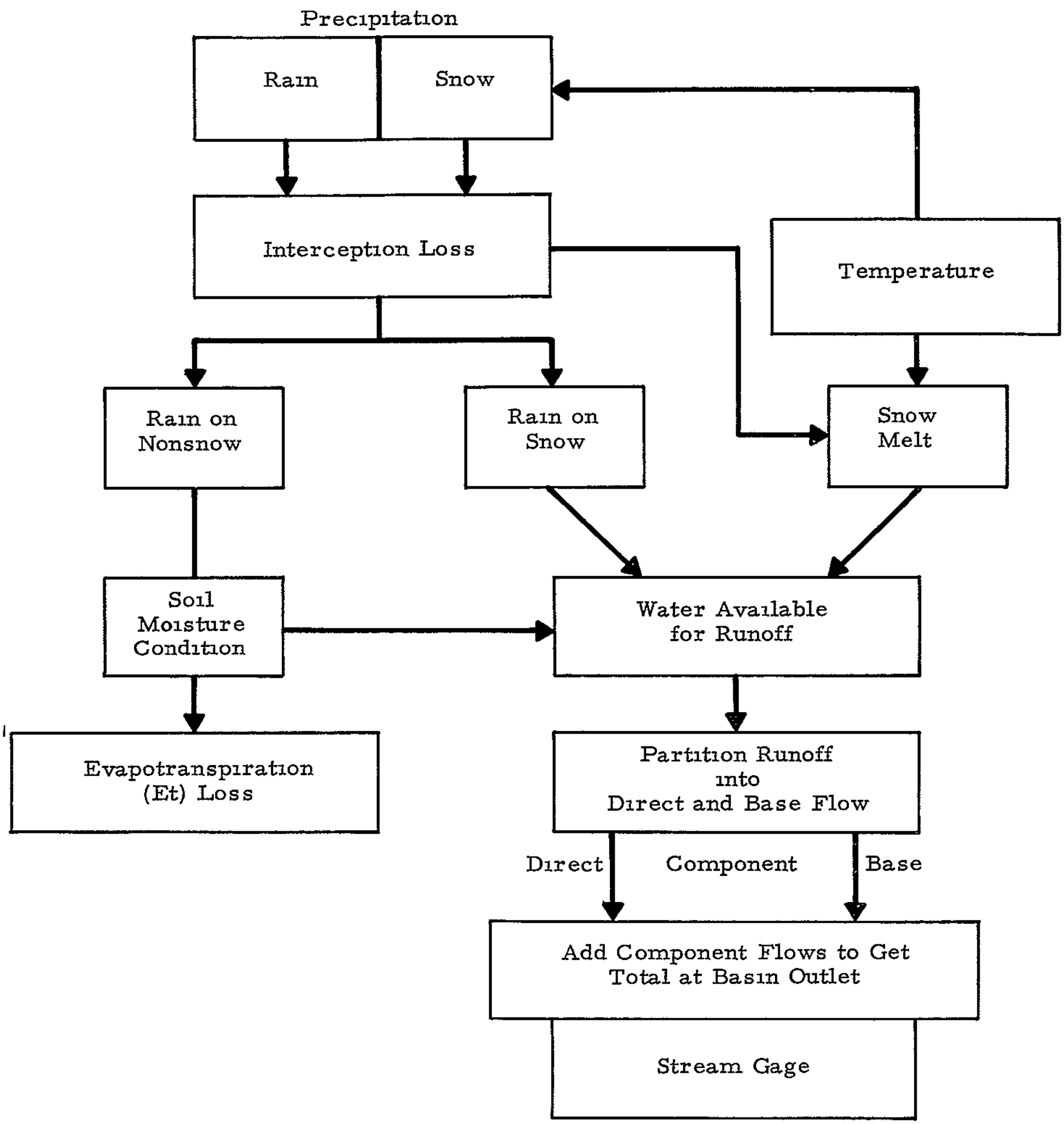


EXHIBIT II-14 SIMPLIFIED SUBBASIN HYDROLOGY MODEL

2 ⊕

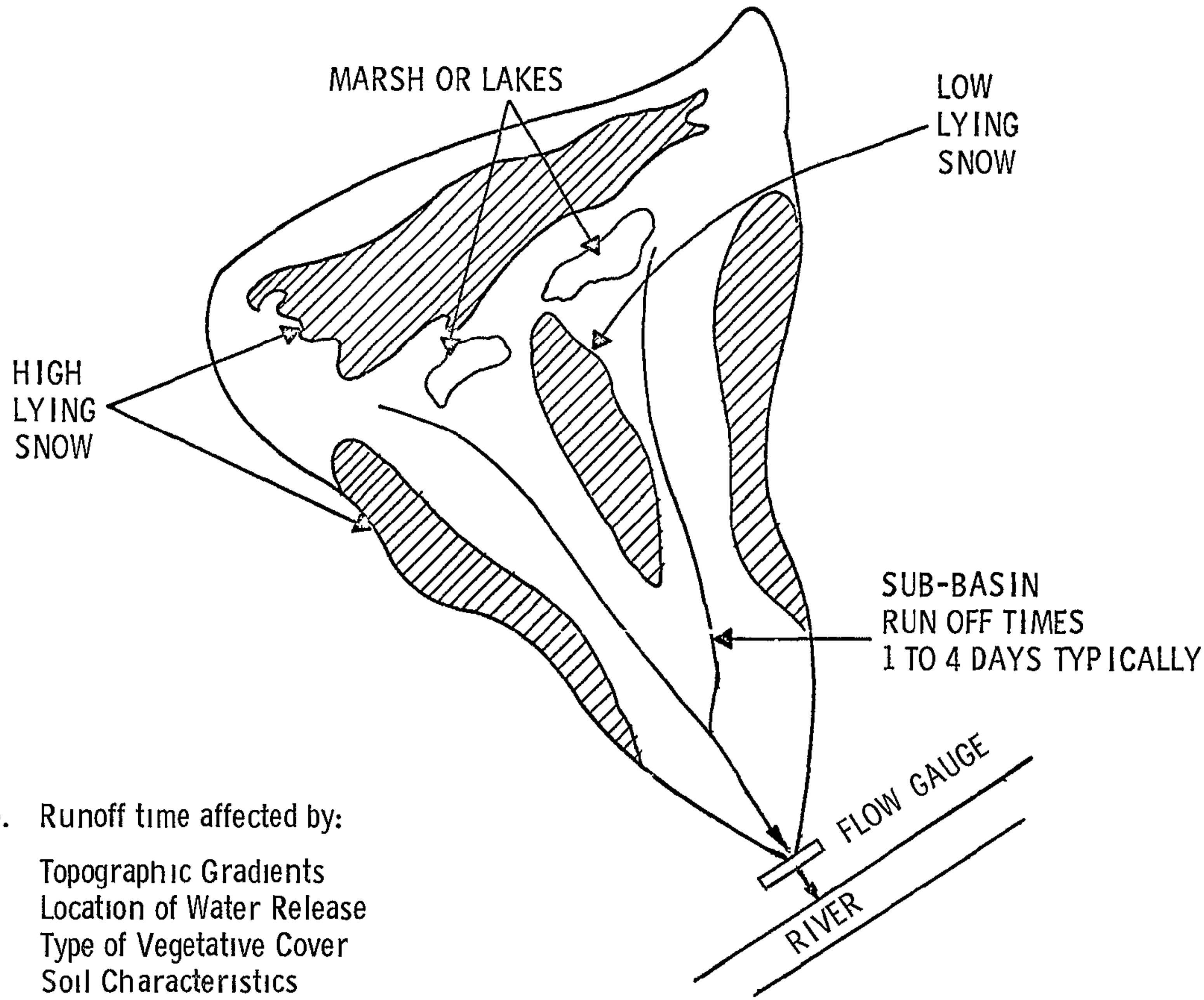
covered by snow (see Exhibit II-15), and thence the fractions of rain which fall on snow and nonsnow This separation is important since once the snow is "primed" (i.e , raised to 32° F) and the underlying soil is thoroughly wetted, rain will pass entirely to runoff The snow also will prevent drying of the soil between rains Trees will tend to be dormant with snow under them and hence transpiration losses will be minimal. In contrast, evapotranspiration effects will be substantial in nonsnow areas. Hence, in nonsnow areas significant portions of each rain will be retained in the soil for subsequent direct return to the air. An account of the current soil moisture condition is kept so that a suitable fraction of such a rain will not contribute to subbasin water flow

A total release of water to streamflow is then computed for each day by adding the three components (snow melt, rain on snow, and rain on nonsnow) The magnitude of each release is used to determine how much will be treated as surface water (fast) runoff and how much as ground water (slow) runoff This is a highly simplified recognition of the complex way in which released water will reach a stream and eventually leave a basin

Each day's release contributes to the outflow on subsequent days, with the outflow on each day being the sum of the contributions from the previous days Exhibits II-16 and II-17 outline the computational procedure described above Each basin's response characteristics are embodied in one or more curves like the one in the center of Exhibit II-16 The size of the day's water input (impulse) is determined from the rain and snow melt analysis, and the resulting schedule of delivery at the outflow gage is computed Exhibit II-17 shows the resulting delivery components and the composite result

This model is only one of many ways of treating the reaction problem It was designed specifically for rapid sensitivity analysis and not to replace any models now in operational use

Exhibit II-18 shows some of the sensitivity analysis results Actual weather records in the Colville Basin were used as inputs. Several factors in the model were varied individually to determine the effects These graphs show the effect on total annual discharge, which is only one of several outputs which could have been displayed. Chart (a)



Note. Runoff time affected by:

Topographic Gradients
Location of Water Release
Type of Vegetative Cover
Soil Characteristics
Antecedent Conditions

EXHIBIT II-15 SUBBASIN SCHEMATIC

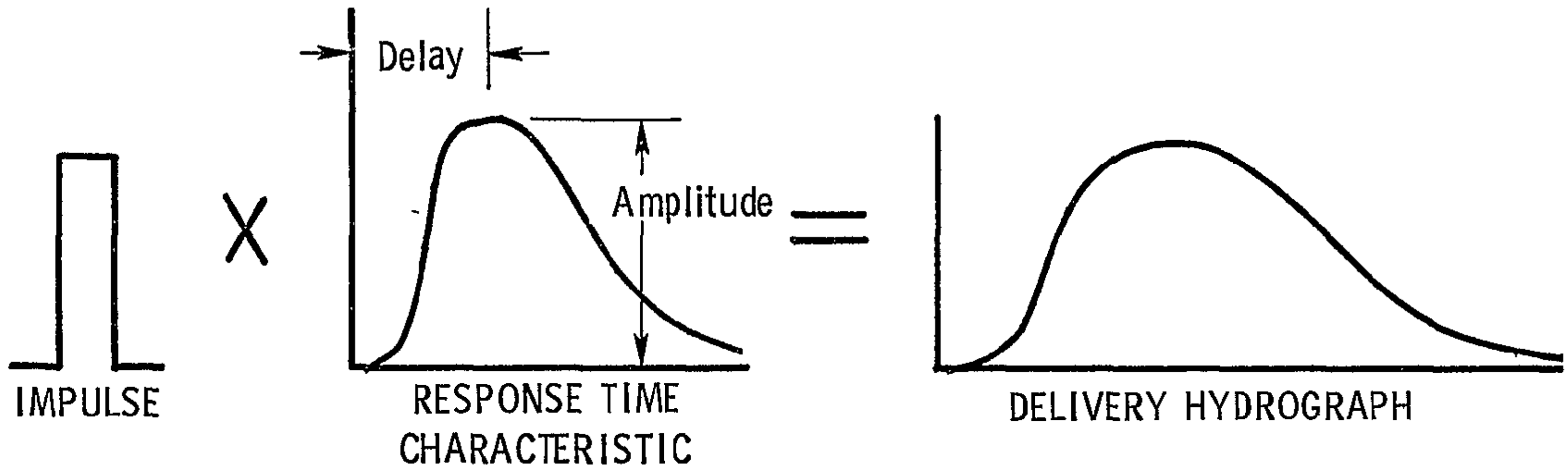


EXHIBIT II-16 INDIVIDUAL PULSE/FLOW RELATIONSHIP

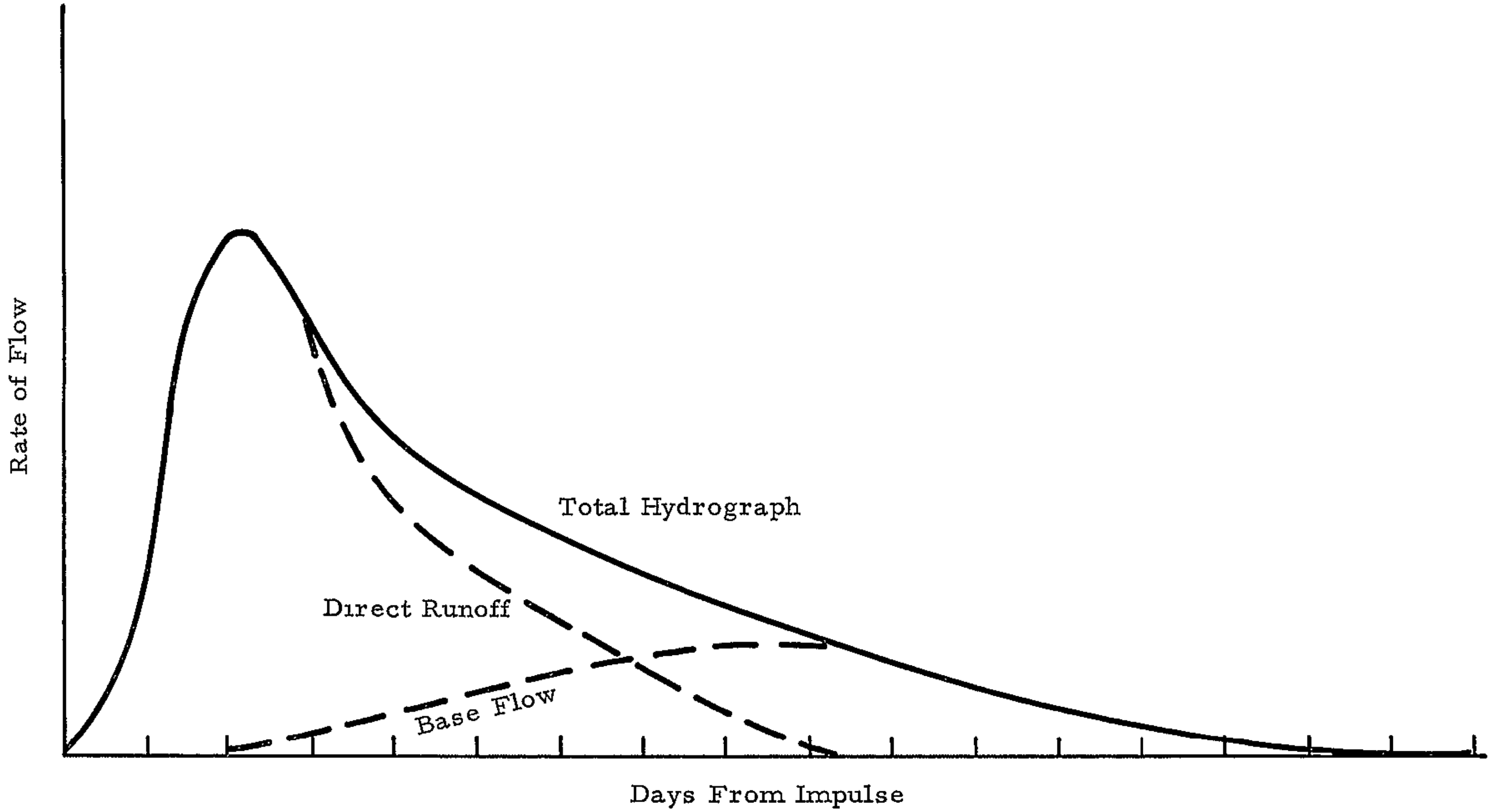
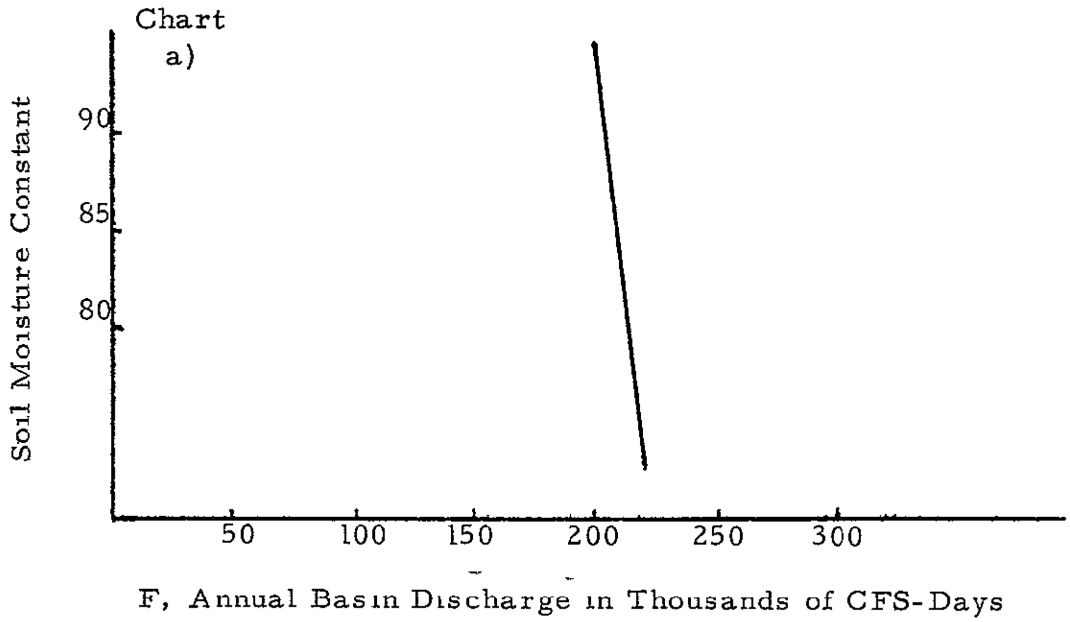


EXHIBIT II-17 TIME DISTRIBUTION OF PULSE



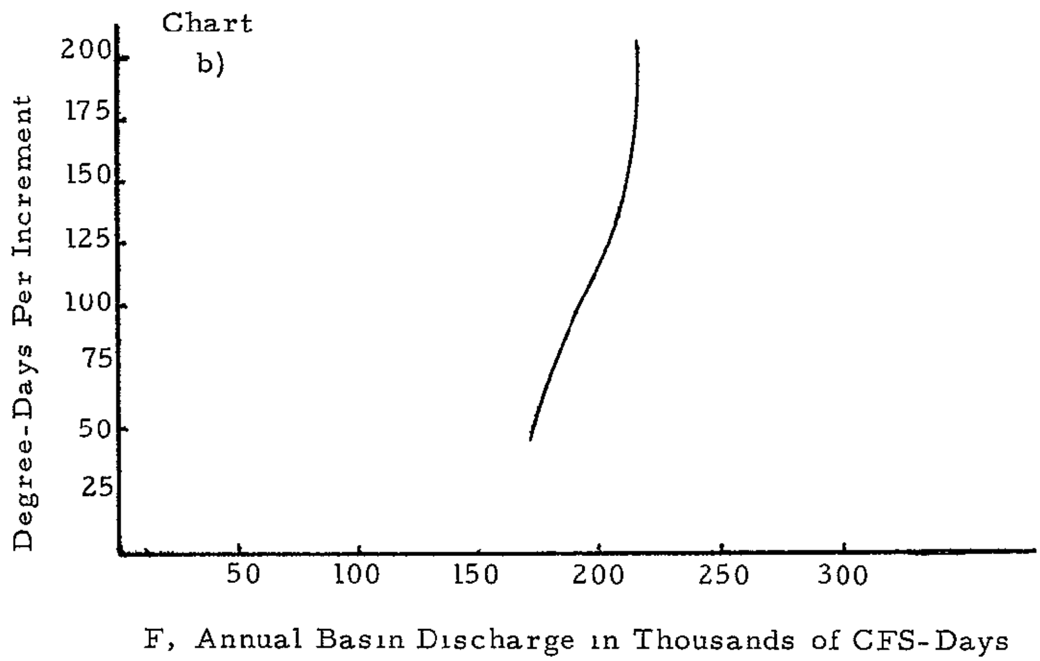
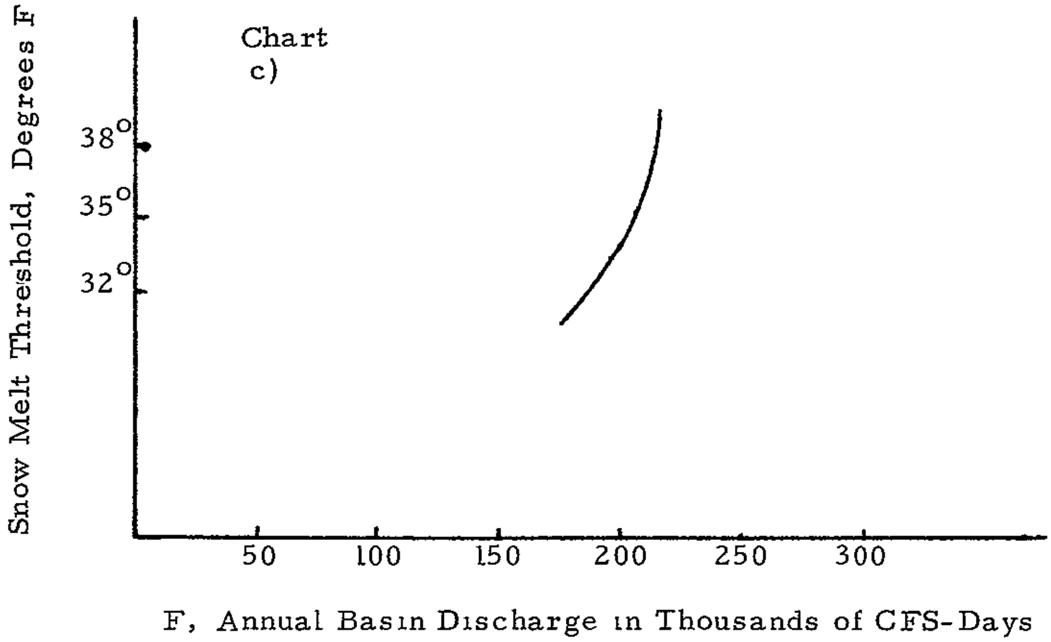


EXHIBIT II-18 SENSITIVITY OF ANNUAL BASIN DISCHARGE TO KEY HYDROLOGICAL VARIABLES



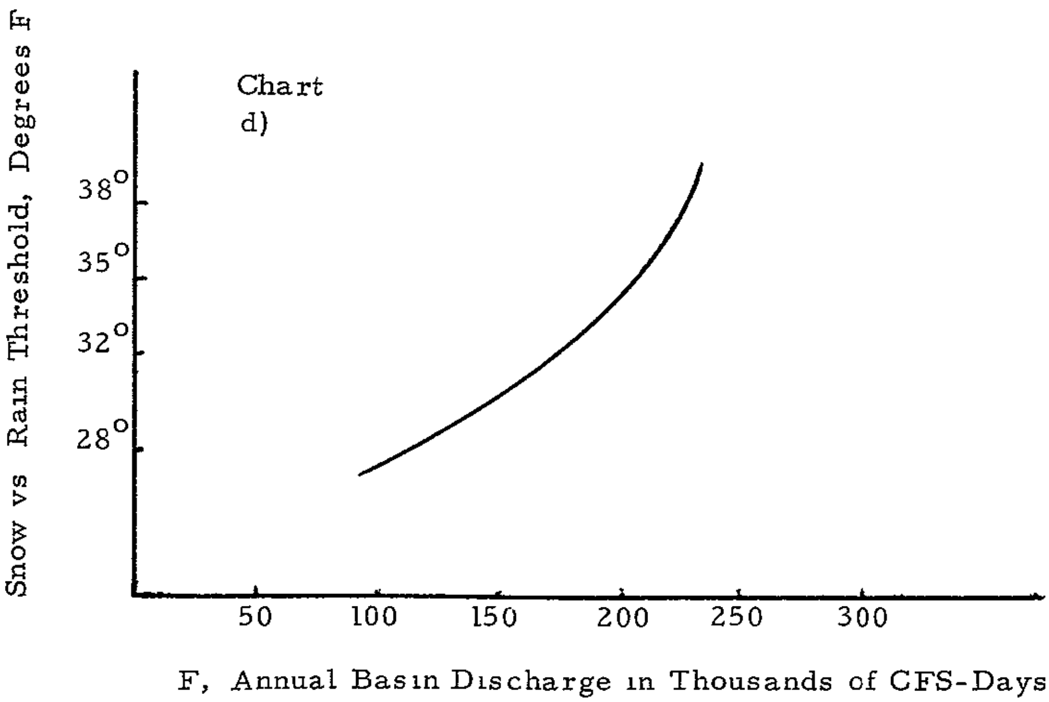
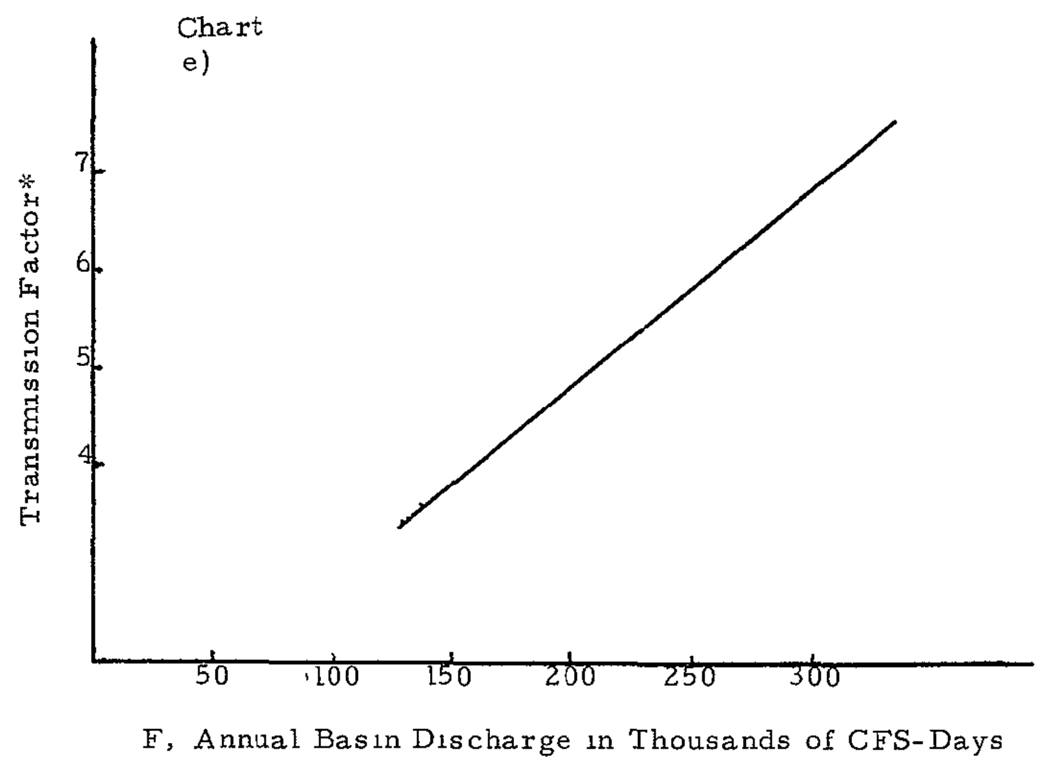


EXHIBIT II-18 (Continued)



*Transmission factor is the fraction of precipitation not intercepted by vegetation

EXHIBIT II-18 (Continued)

of Exhibit II-18 shows the effect of varying one of the major constants in the soil moisture subroutine The implication of the near-vertical slope of the resulting tradeoff line is that an error in soil moisture accounting would have a minor effect

Chart (b) of Exhibit II-18 deals with the rapidity of melt on warm days The principal reason for the change in total output is that the rapidity of melt determines melt completion data and, hence, whether spring rains fall on snow or not

Chart (c) of Exhibit II-18 shows the modeled effect of a change in the melting threshold. Snow will melt when local temperatures are above 32° F. However, actual temperatures, and more importantly, the effective temperatures may vary considerably over a basin A single temperature was used as the input for each basin-day and so this device was used for extension over the basin This approach would be unnecessary with satellite observations. As with the preceding chart, the major issue was whether or not rains fell on snow

Chart (d) of Exhibit II-18 shows the importance of knowing whether a precipitation event was rain or snow (the present model makes this determination based on the temperature for the day). A satellite could resolve this problem, even when it was rain in one part of a basin and snow in another.

Chart (e) of Exhibit II-18 shows the effect of using various precipitation transmission factors A common factor was used in the model for rain and snow It is conceivable that satellite data could be used to assess the interception loss for each storm While this would not complete the analysis by showing how much was transmitted, it could be a big step in improving estimates of storm effects

It can be seen that the total annual discharge computation is not particularly sensitive to assumptions and hence measurements of the soil moisture condition, melt temperature threshold or snow melt rate factor (Charts a, b, and c) That is, substantial variations or errors in these factors did not change the result very much A clear distinction should be made, however, between total annual discharge and daily discharge The rate of discharge on a daily basis is very sensitive to the above factors It is important to know whether precipitation is rain or snow

(Chart d) and what fraction is intercepted by the vegetation (Chart e). Secondly, error effects from one factor may compensate or add to errors in another factor Thirdly, there is no obvious critical error level in any of the factors The factors enumerated and discussed formed the basis for the choice of sensors In particular, the inclusion of the radar system, at relatively great cost, was done as a direct result of the sensitivity analysis performed above

The modeling of the subbasin model for computer application has had several advantages It indicates that the total system can be modeled to accept satellite sensor inputs It permits experimentation with real and hypothetical data It formalizes the runoff sequence to the river gage and permits a review of the critical components It establishes the earth science inputs to the model which must be obtained to use the selected sensors effectively Finally, it permits some sensitivity analysis.

The subbasin hydrographic model described to this point is very useful in understanding the water runoff problem However, it is possible to describe in considerably greater depth the process which has been simplified for computer applications (see Appendix B). The conceptual relationship between satellite observations and stream flows is shown in Exhibit II-19 To convey the complexity of the total process and to obtain some insight into the potential accuracies of the satellite-assisted system, a detailed scenario has been prepared This scenario is a description of a representative subbasin under a representative set of conditions The conditions described are essentially hypothetical but they are typical of what one would find during the season in a particular subbasin

Exhibit II-19 first describes the various components of the scenario model and the sensings or data inputs required to measure these components Surface air temperatures, for example, are a major element in the scenario Determining surface air temperatures is a complicated process and can use various sensings or data inputs From satellite sensing it is important to determine ground temperature patterns, foliage temperature patterns, net radiation, emerging storms and cloud cover A contribution can be obtained from ground data based on

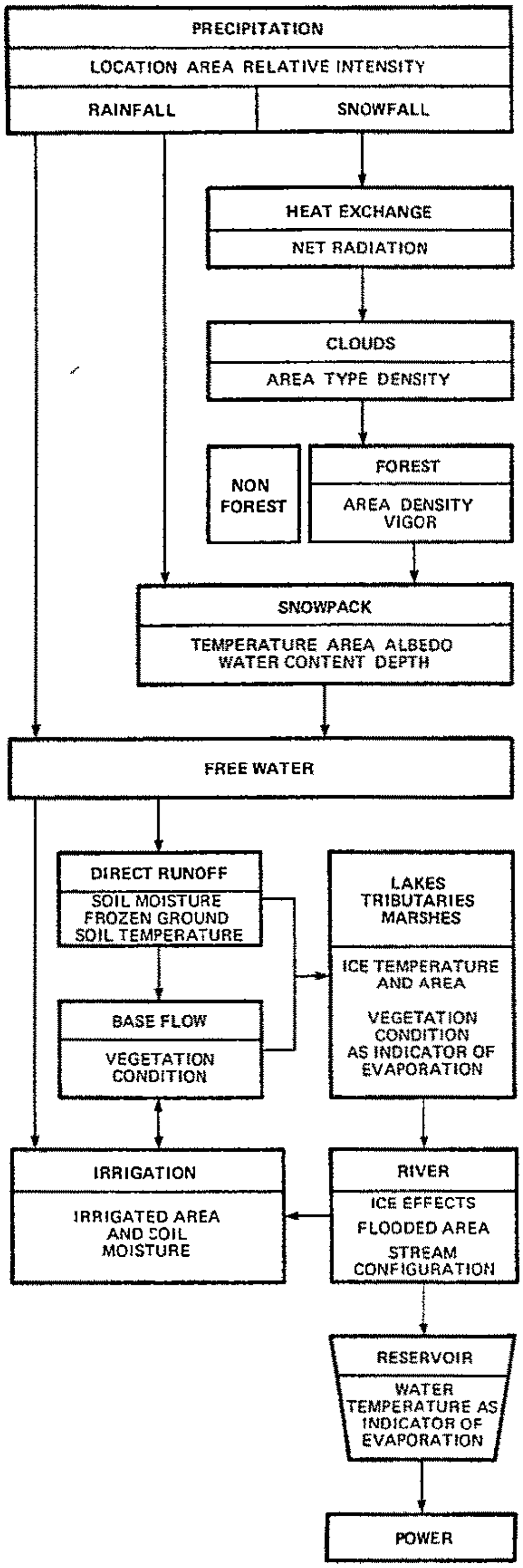


EXHIBIT II-19 SATELLITE OBSERVATIONS AND WATER MANAGEMENT CYCLE

surface and air temperature samplings and local cloud cover readings Exhibit II-19 shows that in addition to air temperature, the following components are important precipitation, intercepts and evapotranspiration, snow water equivalent, snow-covered area, snow melt rates, stream flow rates, soil moisture, water infiltration and percolation

The time-phased scenario is presented in Exhibit II-20 Here the times are specified, the events hypothesized for this typical scenario are described and the associated component of the model specified The times specified are typically one- or two-month intervals, such as November 1 to December 31 The events specified in the scenario relate to the river conditions, meteorological phenomena, etc , expected at these times For example, the river in the November 1 to December 31 period is essentially at low flow stages, runoff may be primarily from ground water despite heavy precipitation as snow, and temperatures may be from 40° F to 15° F for many days The components that are important to these events are such things as stream flow, precipitation and soil moisture, and air temperature The association of times, events and components are summarized then in Exhibit II-21 This summarization reflects a more lengthy text in Appendix B, which describes in considerable detail the typical events summarized in this exhibit

Under the satellite-assisted system, it is projected that four satellites will permit complete coverage of the Pacific Northwest every six hours Thus, large numbers of sensings will be obtained and at any point in the scenario the cumulative number will be large Exhibit II-22 shows the components of the model, the date being considered and the number of sensings or observations By January 1 it appears that the system will have generated, for example, 120 observations of precipitation

e Advantages of Multiple Observations

The identification of the earth phenomenon made on any one pass may be only 90 percent correct Similarly, the

EXHIBIT II-20 HYDROLOGY COMPONENTS OF THE MODEL AND SENSINGS REQUIRED

Component of Model	Sensing or Data Input (Type and Source)
Surface Air Temperature	I Satellite Sensings
	A Ground Temperature Patterns
	B Foliage Temperature Patterns
	C Net Radiation
	D Canadian and Offshore Storms and Basin Cloud Cover
	1 Type
	2 Direction
	3 Temperature
	II Ground Data
	A Surface and Upper Air Temperature Sampling
	B Local Cloud Cover
Precipitation	I Satellite Sensings
	A Precipitation
	1 Type
	2 Area
	3 Relative Intensity
	B Snowpack
	1 Area
	2 Water Equivalent
	3 Albedo
	C Canadian and Offshore Storms and Basin Cloud Cover
	1 Type
	2 Direction
	3 Moisture Content

EXHIBIT II-20 (Continued)

Component of Model	Sensing or Data Input (Type and Source
	II Ground Data
	A Precipitation Sampling
	B Relative Intensity of Precipitation in Some Areas
	C Local Cloud Cover
	D Snowpack Sampling
	1 Area
	2 Water Equivalent
Interception and Evapotranspiration	I Satellite Sensing
	A Vegetation
	1 Type
	2 Area
	3 Vigor
	4 Density
	5 Season (Color)
	B Land Use
	1 Area
	2 Type
	3 Density
	C Surface Temperature
	D Soil Moisture
	II Ground Data
	A Vegetation Sampling
	1 Type
	2 Area
	3 Vigor
	4 Density
	5 Season (Color)

EXHIBIT II-20 (Continued)

Component of Model	Sensing or Data Input (Type and Source
	B Land Use Sampling 1 Area 2 Type 3 Density C Surface Temperature Sampling D Soil Moisture Sampling
Snow Water Equivalent	I Satellite Sensing A Density of Snowpack II Ground Data A Sampling of Snow Water Equivalent
Snow-Covered Area	I Satellite Sensing A Snowfields 1 Area 2 Temperature II Ground Data A Snow Area Sampling
Snow Melt Rate	I Satellite Sensing A Area of Active Melt 1 Area 2 Location 3 Wetness B Foliage Temperature C Net Radiation(Long and Short Wave)

EXHIBIT II-20 (Continued)

Component of Model	Sensing or Data Input (Type and Source
	II Ground Data
	A Area of Activity Melt Sampling
	1 Area
	2 Location
	3 Wetness
	B Foliage Temperature Sampling
	C Net Radiation (Long and Short Wave) Sampling
Streamflow Rate	I Satellite Sensing
	A Stream Configuration
	1 Stream Width, Water Level, and Flooding
	2 Intermittency
	3 Currents
	B Lakes and Marshes
	1 Area
	2 Configuration
	3 Depth
	II Ground Data
	A Streamflow gages
	B Lake and Reservoir gages
Soil Moisture	I Satellite Sensing
	A Diurnal Surface Temperature Variations
	B Vegetation Vigor
	C Soil Water Content

EXHIBIT II-20 (Continued)

Component of Model	Sensing or Data Input (Type and Source)
	II Ground Data
	A Diurnal Surface Temperature Variations Sampling
	B Vegetation Vigor Sampling
	C Soil Water Content Sampling
Water Infiltration and Percolation into the Ground	I Satellite Sensing
	A Soil Types
	B Vegetative Cover
	C Land Use
	II Ground Data
	A Sampling of A, B, and C above
	B Laboratory Infiltration and Percolation Tests

EXHIBIT II-21 HYDROLOGY COMPONENTS OF THE MODEL AND EVENTS FROM SCENARIO

Time	Event from Scenario	Component of the Model
1 Nov-31 Dec	River is in low flow stages	Streamflow
	Runoff is primarily from ground water despite heavy precipitation as snow Rain is lost to soil moisture deficit	Precipitation and Soil Moisture
	Mean daily temperatures drop from 40° F to 15° F for several days	Air Temperature Soil Moisture Water Infiltration and Percolation
	Seasonal snowpack begins to accumulate	Snow-Covered Area and Snow-Water Equivalent
	Nineteen cloud-free days during the 2 months	Snow Melt Rate and Surface Air Temperature
	Several days with temperatures below 20°F freezes water in shallow basins and in stream margins	Surface Air Temperature and Streamflow
	Deciduous trees have changed color and are almost leafless	Evapotranspiration and Interception
1 Jan-31 Jan	Streamflow remains low with only a minor increase in the middle of the month	Streamflow
	Runoff is primarily from ground water with some minor runoff associated with the storm in mid-January	Streamflow
	Precipitation is heavy especially between 12 Jan and 26 Jan	Precipitation
	Snowpack continues to increase in depth and area	Snow-Covered Area and Snow-Water Equivalent
	Monthly mean temperature for Jan is below freezing with some days below zero	Streamflow and Surface Air Temperature
	Deciduous trees are bare	Evapotranspiration and Interception
	Eight cloud free days during the month	Snow Melt Rate Surface Air Temperature
1 Feb-31 Mar	Extremely low temperatures cause a minor reduction in streamflow on Feb 18	Streamflow
	Mean daily temperature is about freezing during March	Surface Air Temperature
	Precipitation during Feb and March is light and falls as snow	Precipitation
	Snowpack continues to build with the maximum level reached in March	Snow Covered Area and Snow-Water Equivalent
	Deciduous trees are bare and coniferous trees have lost some color	Evapotranspiration and Interception
	Evapotranspiration rate is near zero	Evapotranspiration
	Twelve cloud-free days in 2 months	Snow-Melt Rate Surface Air Temperature
1 April-23 April	Precipitation is light snow and rain	Precipitation Infiltration and Percolation
	Rainfall is on snowpack rather than on bare ground	Streamflow
	Mean daily temperatures are above 40°F	Surface Air Temperature and Snow Melt
	Snow melt runoff begins as does rainfall runoff	Snow melt
	Ten cloud-free days	Surface Air Temperature and Snow Melt
	Snowpack begins to diminish	Snow-Covered Area Snow-Water Equivalent
	Deciduous trees begin to leaf and coniferous trees show new light-green growth	Evapotranspiration and Interception
1 April-23 April (Continued)	Evapotranspiration rate begins to increase	Evapotranspiration
	Streamflow increases to five times that of February	Streamflow
23April 29 April	Eastern Pacific storm develops	Precipitation
	Light rain falls mostly on snow covered areas	Precipitation Infiltration and Percolation
	Mean daily temperatures rise to 50° F	Surface Air Temperature Snow Melt
	Snow-covered area decreases	Snow-Covered Area Snow-Water Equivalent
	Streamflow increases to more than double that of the previous 23 days	Streamflow
	Evapotranspiration increases but does not affect runoff significantly	Evapotranspiration and Interception
	One cloud-free day	Surface Air Temperature and Snow Melt

EXHIBIT II-22 STREAMFLOW FORECAST OF FLATHEAD RIVER BASIN - TIMING AND NUMBER OF SENSINGS AS EACH EVENT OCCURRED

	Surface Air Temperature	Precipitation	Interception and Evapotranspiration	Snow Water Equivalent	Snow-Covered Area	Snow Melt Rate	Streamflow Rate	Soil Moisture	Water Infiltration and Percolation Into the Ground	Probable Climate or Weather	Confirmation	Correlation and Comparison
1 Nov - 31 Dec												
River is in low flow stages							76					
Heavy precipitation falls as snow		120						120	120			
Mean daily temperatures drop from 40°F to about 15°F for several days	90											
Snowpack accumulates				76	76							
Nineteen cloud-free days	30							30				
Several low-temperature days - temporary ice storage							30					
Deciduous trees have changed color and are leafless			76									
Climate and weather prediction estimates normal precipitation to May 1										1		
Jan 1												
Analysis is performed											1	1
Jan 1 Issue Prediction of Total Seasonal Water Runoff to July 1												
Cumulative number of sensings	120	120	76	76	76	76	106	150	120	1	1	1
1 Jan - 31 Jan												
Minor increase in flow in the middle of month							8					
Ground water flow									8			

EXHIBIT II-22 (Continued)

	Surface Air Temperature	Precipitation	Interception and Evapotranspiration	Snow Water Equivalent	Snow-Covered Area	Snow Melt Rate	Stream Width	Soil Moisture	Water Infiltration and Percolation Into the Ground	Probable Climate or Weather	Confirmation	Correlation and Comparison
12 Jan - 26 Jan												
Heavy precipitation of snow		24										
Snowpack increases in depth and area				68	68							
Very low temperatures with mean temperature below freezing	68											
Deciduous trees are bare			32									
Eight cloud-free days						32						
1 Feb - 31 Mar												
Mean daily temperatures about 22°F in February							28					
Mean daily temperatures about 32°F in March							31					
Light precipitation of snow		72										
Snowpack accumulates to maximum in Marcn				72	72							
Extremely low temperatures reduce stream flow							4					

EXHIBIT II-22 (Continued)

	Surface Air Temperatures	Precipitation	Interception and Evapotranspiration	Snow Water Equivalent	Snow-Covered Area	Snow Melt Rate	Streamflow Rate	Soil Moisture	Water Infiltration and Percolation Into the Ground	Probable Climate or Weather	Confirmation	Correlation and Comparison
Feb 18												
Deciduous trees bare			72									
Coniferous trees have some color			72									
Twelve cloud-free days						48						
Evapotranspiration rate near zero			72									
Climate and weather predictions estimate normal temperatures and precipitation to May 1										1		
April 1												
Analysis is performed											1	1
April 1 Issue Prediction of Total Seasonal Water Runoff to July 1 Issue Forecast of Daily Streamflow Through May 1												
Number of sensings (Jan 1 - April 1)	68	96	248	140	140	80	71		8	1	1	1
Number of previous sensings	120	120	76	76	76	76	106	150	120	1	1	1
Cumulative number of sensings	188	216	324	216	216	156	177	150	128	2	2	2

resolution of the sensor may be something like 1, 200 feet Thus, on any one pass, the value of the information must be degraded by these factors Exhibit II-23 denotes a typical representation of system performance in this regard.

On the other hand, in an operational context such as described in the scenario, it is easy to see that we will often have repeated observations on the same phenomenon If we are observing the same state of nature, cumulative observations rapidly reduce the error term and increase our confidence as Exhibit II-23 shows

Repeated observations also make a very significant contribution in increasing the effective resolution of the system The formula under II of Exhibit II-23 indicates that as the number of observations goes up, the resolution error decreases

Under an operational setting, it is possible to obtain several independent observations of the same phenomenon For example, the snow pack may be melting and releasing a particular volume of water This volume of water may be observed in (1) a reduction in area of snow field, (2) calculated area, given temperature, winds, rain, etc., and (3) increased size of marshes, lakes, or river flood plains In this case, three independent measures of the same phenomenon are being obtained See C of Exhibit II-23 and the example in Appendix B

The sensors frequently are much more accurate in measuring relative differences than absolute quantities If it is possible to calibrate one of several satellite precipitation observations against a ground observation, relative differences between satellite observations can readily be converted into absolute quantities.

The large number of observations obtainable from the satellite also permit the development of new predictive patterns. With increased observations over a considerable period of time, it will be possible to develop a more accurate subbasin precipitation model using a given storm size, wind speeds and direction, topography, and temperatures Further, as we move closer to the predicted period, it will be possible to add more and more variables so that predictive accuracy increases significantly

EXHIBIT II-23 CORROBORATING TECHNIQUES INCREASING SYSTEM PERFORMANCE (TYPICAL REPRESENTATION)

A Improved Identification

Number of Observations	Probability of Correct Identification[1]	Probability of False Identification[2]
1	90	01
2	99	001
3	999	0001
4	9999	00001

B Reduction of Resolution Size Error

$$\text{Resolution Error} = \frac{\text{Resolution in Feet}}{\sqrt{\text{No of Observations}}}$$

C Multiple Independent Estimates

Volume at Snowmelt

1 Observed reduction in snowfield area

2 Calculated area given temperature, winds, rain, etc observations

3 Increasing size of marshes, lakes, river flood plains, etc

D Absolute Measurements Improved by Relating Highly Accurate Relative Measures to One or More Earth Truth Values

E Volume of Observations Allows Development of New Predictive Techniques (e g , Subbasin Precipitation Given Storm, Windspeeds, and Direction, Topography, and Temperatures)

[1] Type I error

[2] Type II error

The final output of the subbasin modelizing would be a Moving Forecast Scale This tool has been proposed as the cumulative result of the sensor observations and subbasin analysis available for managerial decisionmaking purposes Exhibit II-24 below shows a typical Moving Forecast Scale (MFS) It is also reasonable to propose that an error envelope can be developed around the MFS Within periods that are shorter than the subbasin routing times, the MFS should be very accurate Given medium range meteorological or climatological forecasting[1] and seasonal snow melt, longer range forecasting can be made

In the analysis above a number of arguments have been made as to why the MFS should be quite accurate Sensor probabilities of detection and resolutions were extrapolated to satellite altitudes It was noted that repeated observations of the same phenomenon are possible A number of pattern recognition techniques and corroborating estimating procedures were described above Further, the possibilities for developing meteorological and other estimating techniques by subbasins or portions thereof was suggested Three subbasins were examined to determine the general ability of sensor to detect and furnish timely information Finally, a complicated scenario was prepared to show the interrelationship of the above and the apparent overall system accuracy that should eventually emerge

This projected overall system accuracy cannot, however, be attained without a considerable research and development expenditure These expenditures will be substantially developmental, since basic research does not seem to be required Further, it is apparent that there is no critical component or critical path which, if not successfully researched, would prevent the realization of the overall system Actually, it looks as if failures in given areas of research are likely to be balanced by successes in other areas The ultimate success of the overall program can be judged to be high

There are obviously a host of research problems that must be solved before the MFS can be constructed with its envelope of probable error Some of the most pressing problems are as follows

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[1] See Appendix B for a discussion of weather forecasting accuracy

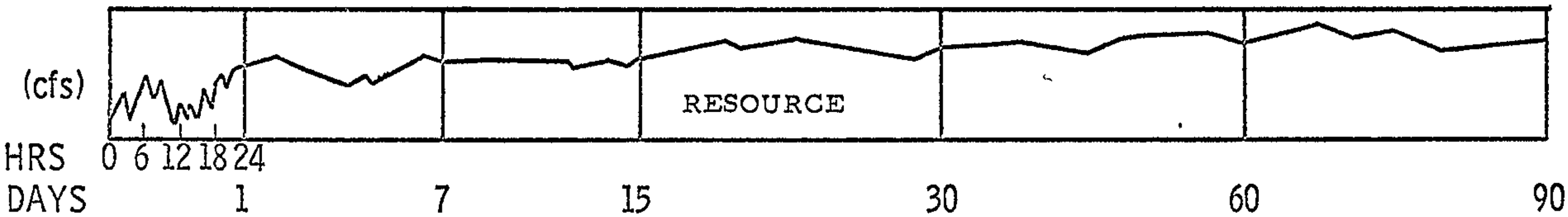


EXHIBIT II-24 MOVING FORECAST SCALE RESOURCE

- Probability of sensor identification and false alarm rates at satellite altitudes
- Sensor resolution at altitude
- Sensor capabilities to measure intensity of rain storms
- Description of snow area patterns associated with different snow volumes
- Indicators of snow depth and water equivalent
- Formulae for estimating volumes and water equivalents from observable data
- Calibration of areas of marshes, lakes, flood plains, etc , as a function of stream flows
- Development of subbasin meteorological predictive models
- Establishment of the degree of corroboration of independent estimates of snow pack melt

Without the results of the research implied above, it is clearly not possible at this time to reasonably quantify the MFS and its error envelope hourly, daily, weekly, monthly, or seasonally for each subbasin

Even without the fully quantified MFS it is important to estimate the benefits to water managers of such a tool This in turn would substantiate the need and justification for undertaking the research program It also allows the research manager to judge the value of the overall success of the R&D program and the relative importance of successes or failures in specific research tasks Thus, the river model below assumes tha. the MFS can in fact be developed to the level of accuracy required for short-, medium-, and long-term management requirements

(It may be noted at this time that the same type of argument must be made for the wheat inventory/yield case and rust cases treated below The success of certain developmental research is assumed in calculating potential benefits)

2 River User Decision Model

a Problem and Analytical Approach

The subbasin model described in the preceding section has made it possible to relate measurable input phenomena such

as precipitation, temperature, etc , to resulting subsequent stream flows The output of the subbasin model may be thought of as a forecast of water flows into the river system over time, with error terms attached to the flows forecast for each period The errors in forecast inflow quantities are expected to be quite small, because of the widespread coverage afforded by the satellite system, the repeated measurements of each input phenomena, and the development of techniques of pattern recognition (explained above) Individual subbasins can vary markedly in terms of physical characteristics, and thus, in their input/output behavior

The most relevant manifestation of the subbasin variations can be conveniently summarized as first, the routing of an input, and secondly, the subbasin reaction time, i e , the time required for an input at one end of the subbasin to reach the "output" point at the other end These characteristics have been treated in detail in the subbasin model They are mentioned here to point out the possibilities for developing "lead times" in subbasin output forecasts. Added to the lead time picked up in the subbasin per se, the forecast lead time for flow at a given point in the river can be lengthened by the meteorological forecast of precipitation into a subbasin and by the time it takes for the output of a given upstream subbasin to flow along the main river stem to that point

The most important inflow forecasts, from the point of view of power management, are short-term forecasts (up to 2 days), and seasonal cumulative inflow forecasts (up to 6 months) The satellite system will contribute greatly to both these requirements On the other hand, it is not necessary to forecast flow perfectly at daily intervals over any great length of time, say, the total water season If the season as a whole can be predicted to be, say, wetter than average, daily operations can incorporate this forecast Short-term deviation can be accommodated by the inherent flexibility in storage capacity, ability to pick up the load demands at different dams, and so on

Ultimately, an information and forecast system could be developed with the satellite system to generate outflow forecasts for every subbasin and for each relevant partition of a subbasin That is, exhaustive

forecasts of every input to the entire river could be generated, and power schedules could be built on these expected inflows

In the interest of reaching valid general conclusions within the scope of the current study, however, no attempt was made to detail the river system in its entirety Rather, it was recognized that a simplified model of the system would suffice for the analysis, without doing violence to important relationships This model will be presented below.

The improved forecasting capability indicated was then applied to this river system model to determine the general areas in which benefits would accrue to power management and to prepare an estimate of the dollar value of these benefits

b Simplified River Model

As mentioned, it was decided not to treat with a completely detailed and exhaustive description of the Columbia River system, but rather with a simplified model Benefits are actually estimated on the basis of two simplified models, one representing the present system, and the other representing the same system with the additional storage and capacity planned and under construction for the 1970's Both models are series-connected dams and assume a one-way increasing flow from source to mouth They are shown schematically in Exhibit II-25

There are three types of dams on the Columbia River system, differentiated by their storage capacity relative to annual flows The first type is the annual dam, represented by "A" in Exhibit II-25 This type of dam has a relationship of storage to annual flow that assures that even a very low spring inflow will be sufficient to refill it Examples are Grand Coulee and Chief Joseph The second type of dam is the Run of the River dam (ROR), and it is indicated by "R" in Exhibit II-25 These dams have negligible storage capacity Any water that flows into the river behind such a dam cannot be held, but must flow through Examples of RORs are Bonneville, The Dalles, and McNary

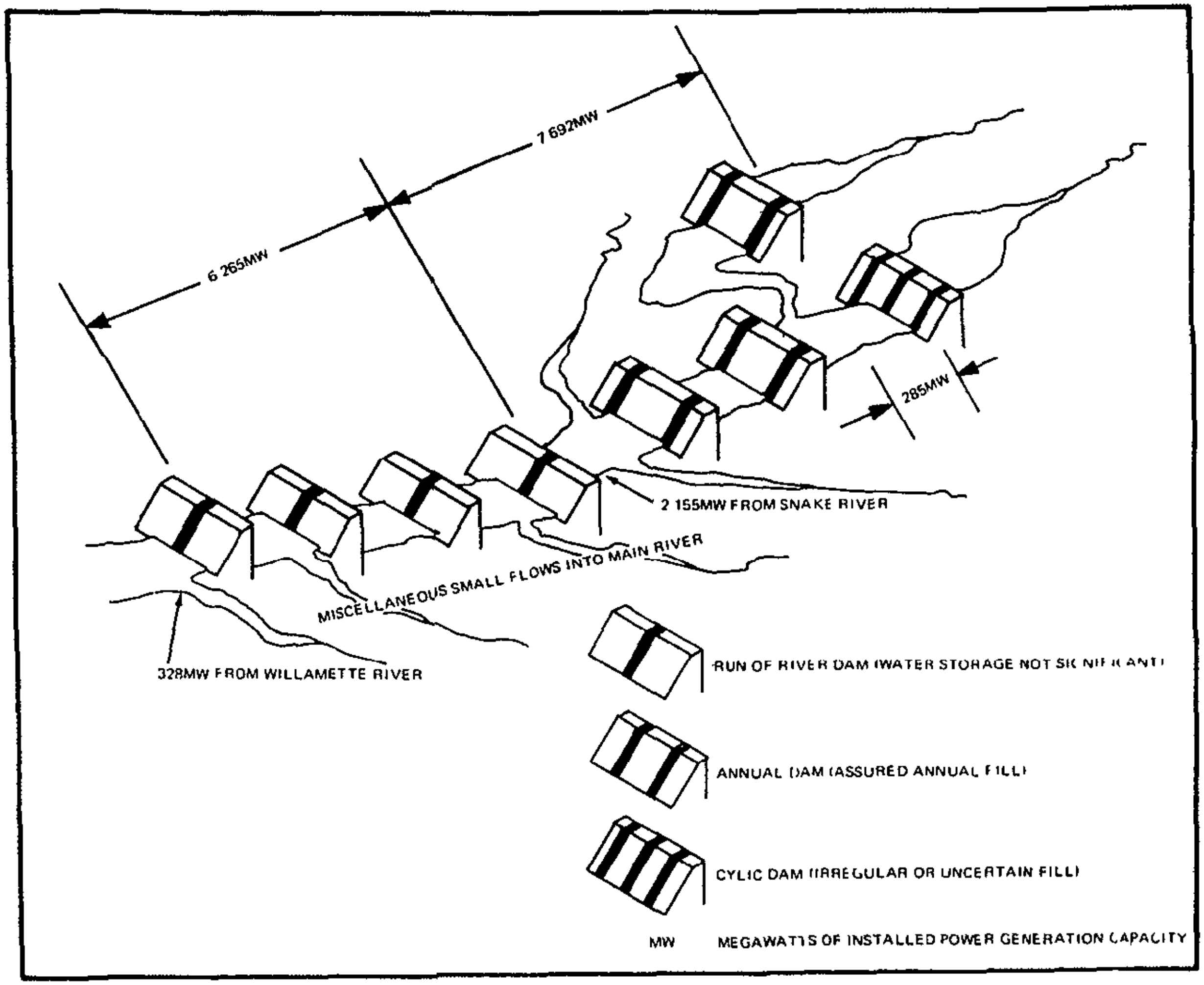


EXHIBIT II-25 SCHEMATIC REPRESENTATION OF THE COLUMBIA RIVER

The third type of dam is the cyclic dam These dams have large storage capacities relative to annual flows that they experience, and refill is not assured under low inflow conditions These dams generally are found at headwaters, where flows, though substantial, are still small relative to the cumulative flow at the mouth of the river These are indicated in Exhibit II-25 as C An example is Hungry Horse, and under construction are Arrow, Libby, and Mica

The model of the present system consists of six dams, of which three are run-of-the river, two are annual, and one is cyclic They are, ascending from mouth to source, Bonneville, The Dalles, McNary, Chief Joseph, Grand Coulee, and Hungry Horse In terms of installed generating capacity the three RORs contribute 44 percent of the total installed capacity modeled of the Columbia River system, the annuals contribute a little over 50 percent and the cyclic 5 percent Altogether these six dams represent 80 percent of the total installed Federal capacity (The remainder is installed on the Upper Snake and the Yakima Rivers which are not included Also excluded was the non-Federal installed capacity between Chief Joseph and McNary)

The model more appropriate in the future includes the dams shown above plus two additional ones, John Day, an ROR, and Libby, an annual Two of the dams in Canada are not shown, as they are storage dams with no installed generating capacity This new configuration accounts for 85 percent of the expected 1975-1980 Federal installed capacity on the Columbia River system

Further detailing of the models would increase the accuracy of evaluation only marginally for our purposes Ideally, different power sequences evaluated over historical 20-year flow rates on a month-by-month basis at each generating station would quantify benefits with greater accuracy However, this analysis is concerned with the general magnitude and kinds of benefits that would accrue with better forecast information Hence, the models used will suffice for evaluating differences in management with the satellite-assisted information system

The working of the river model can be demonstrated by noting the time required for water inputs to travel from one point to another

Exhibit II-26 is a general schematic representation of river travel times Also noted are the subbasin reaction times From the exhibit it will be seen, for example, that a rain input to the South Flathead Fork River Basin will take 28 hours to reach the main stream, and, subsequently, 81 hours to reach Bonneville Dam Similarly, an input into the Colville River Basin will take 4 days to reach the Columbia River, and 23 more hours to reach Bonneville Dam To these lead times might be added at minimal 2-day meteorological forecast giving total lead times of about 5 days

Not all water inputs to the main stream come from streams Sizable quantities of water enter the main stream between gaged streams The magnitude of this local ungaged inflow between various gaging points along the river is shown in Exhibit II-27

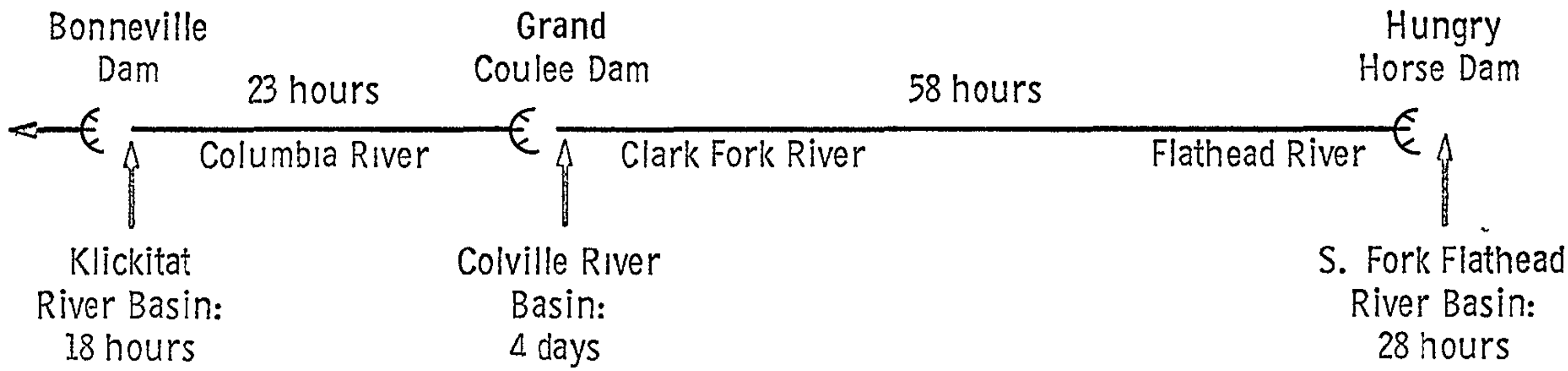
As indicated above, the satellite can greatly assist in improving the quality and accuracy of short-, medium-, and long-term seasonal forecasts In the hydrogeneration of power, these forecasts have different values to different operations and types of dams

The shorter term forecasts (up to 2 days) are the most important elements of day-to-day generation scheduling involving

- Operation of the run-of-the-river dams (RORs) (no storage)
- Operation of dams with pondage (limited 2 to 3 day storage)
- Interdam coordination of RORs (to maximize head and minimize spill)
- Efficient matching of water resources and anticipated load demand

Medium- to long-term forecasts (including seasonal cumulative flow) are especially important for

- Operation of dams with sizable reservoirs (seasonal storage)
- Operation of dams whose drawdown is a function of anticipated refill (cyclic dams)
- Coordination of drawdown and refill-hold of series-connected reservoir dams



Total time for a rainfall excess in the S. Fork Flathead Basin to reach Bonneville Dam = 109 hours.

* Assuming instantaneous flow through reservoirs and regulated lakes.

** Time between first rainfall excess and the peak discharge at basin outlet.

EXHIBIT II-26 RIVER TRAVEL TIMES* AND TRIBUTARY SUBBASIN REACTION TIMES** DURING MEAN JUNE FLOWS (1951-60)

EXHIBIT II-27 UNGAGED LOCAL INFLOW COLUMBIA RIVER BASIN

River Gaging Points	Ungaged Local Inflow as a % of Flow at Downstream Gage (Average annual flow 50 yrs)	Ungaged Local Drainage Area (Mi^2)
Upper Columbia		
Birchbank, B.C.-Revelstoke, B.C	16.2%	5,700 mi^2
Kettle Falls, Wash -Birchbank, B C	7 7	1,140
Grand Coulee-Kettle Falls	0.3	950
Lower Columbia		
Grand Coulee-Trinidad	0.7	2,675
Trinidad-Umatilla	0 0	2,290
Dalles-Umatilla	0 0	2,870
Bonneville-Dalles	0 5	844
Snake:		
Milner-Heise	5.4[1]	9,520
Weiser-King Hill	1.6	5,880
Clarkston-Weiser	10.0	3,650
Mouth-Clarkston	0.6	2,820

Note (1) Should be much less (~ 3%) because of irrigation divisions lowering flow at Milner

From Water Resource Development, Columbia River Basin, Vol. 1. U S. Army Corp of Engineers, June 1958.

Short- and long-term forecasts are interdependent, as short-term operations will affect the seasonal operation Short-term operation is also an input for the long-term operating strategy Long-term strategy, moreover, will influence daily operations, especially secondary power sales

D. System Operation and Benefits

1 Hydroelectric Power Benefits

For improved forecast information to produce benefits, the management information system into which the improved information is introduced must be capable of using it Exhibit II-28 shows the present management system for hydrogeneration as described by the BPA. This system is basically geared to short-term hourly load-resource operation and is somewhat insensitive to informational inputs, largely because the availability and accuracy of information have up to now been low.

Exhibit II-29 outlines a management system that is very sensitive to forecast information and that can be used with better and more accurate information Note that management involves both short- and long-term operation and that the two are interdependent. Moving forecast scales are used for supply and demand (through temperature and overcast prediction) for both long- and short-term hydrogeneration. Unlike the present management system, the system outlined in Exhibit II-28 provides a rational tool for long-term planning of power sales based on observations of current phenomena that will determine future runoff.

Improved information and forecasting can contribute to the operation of each of the types of dams described above First consider the RORs Judicious upstream releases will tend to maintain an optimum head at the dam By minimizing the fluctuations in head, maximum generating efficiency can be maintained (i.e , maximum KW/CFS) Accurate forecasts of factors such as upstream releases for power, interdam subbasin flows, power peak versus time of day, will enable managers to approach optimum ROR operation.

Second, consider the dams with annual reservoirs. Each water year is divided into two periods in one period the flow into the reservoirs is less, and in the other, greater, than required for the dam's potential power output For each annual dam a critical rule curve has been developed. The benefits of long-term forecasting will occur when storage drawdown and refill plans can take account of future expected flow. A better drawdown schedule would permit greater utilization of

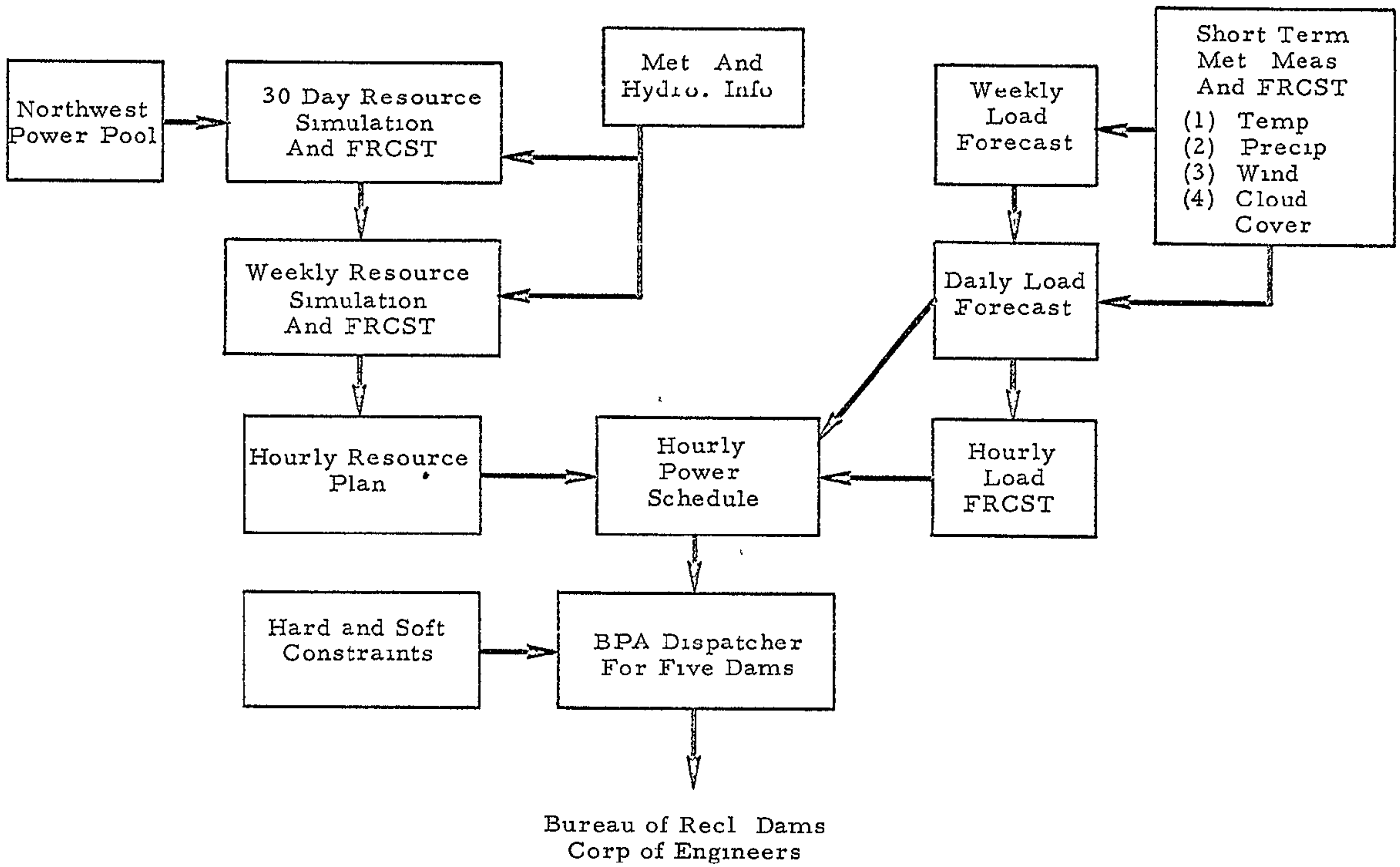


EXHIBIT II-28 PRESENT BPA SYSTEM SCHEDULING AND FORECASTING

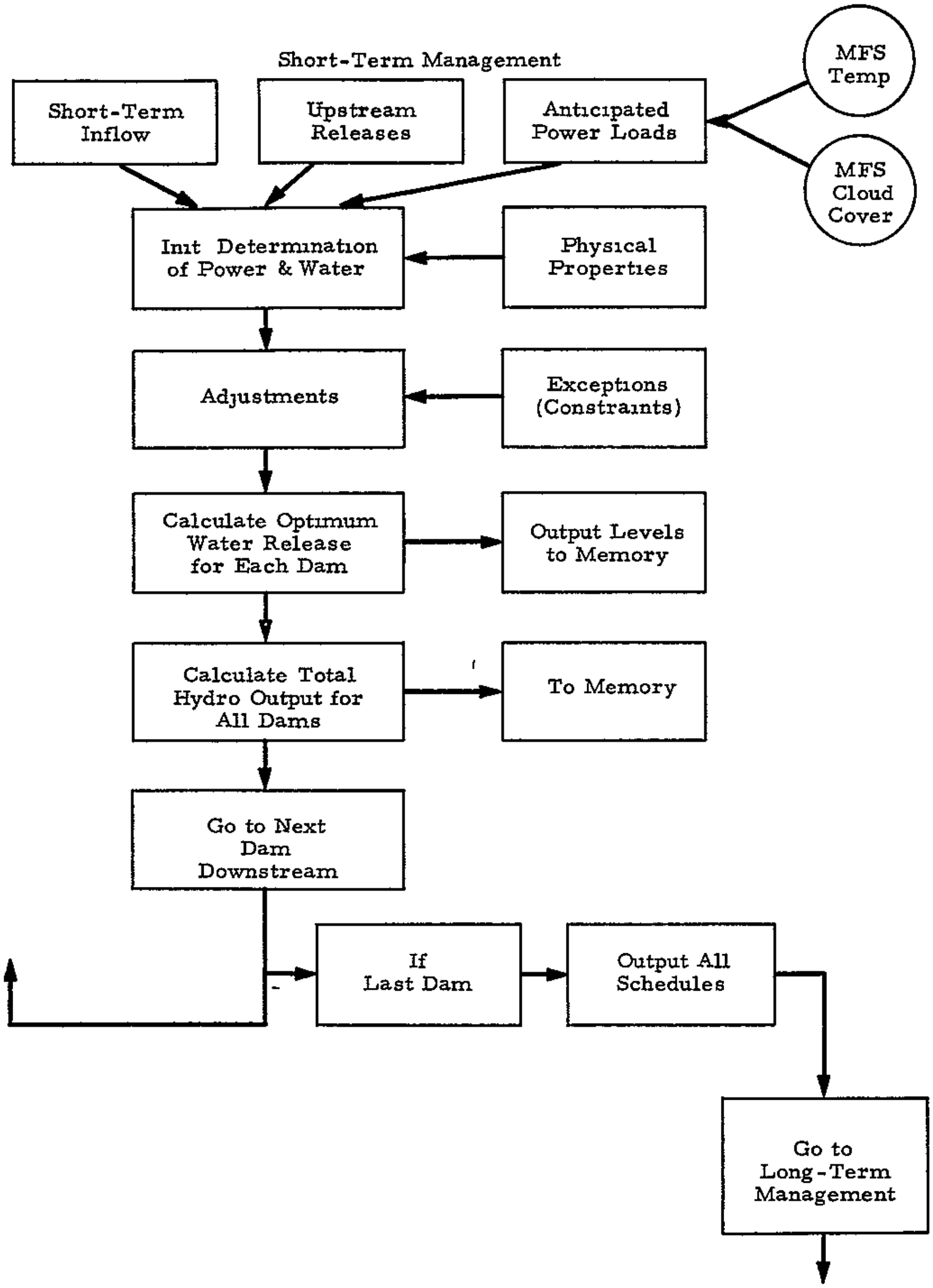


EXHIBIT II-29 FORECAST-SENSITIVE MANAGEMENT SYSTEM

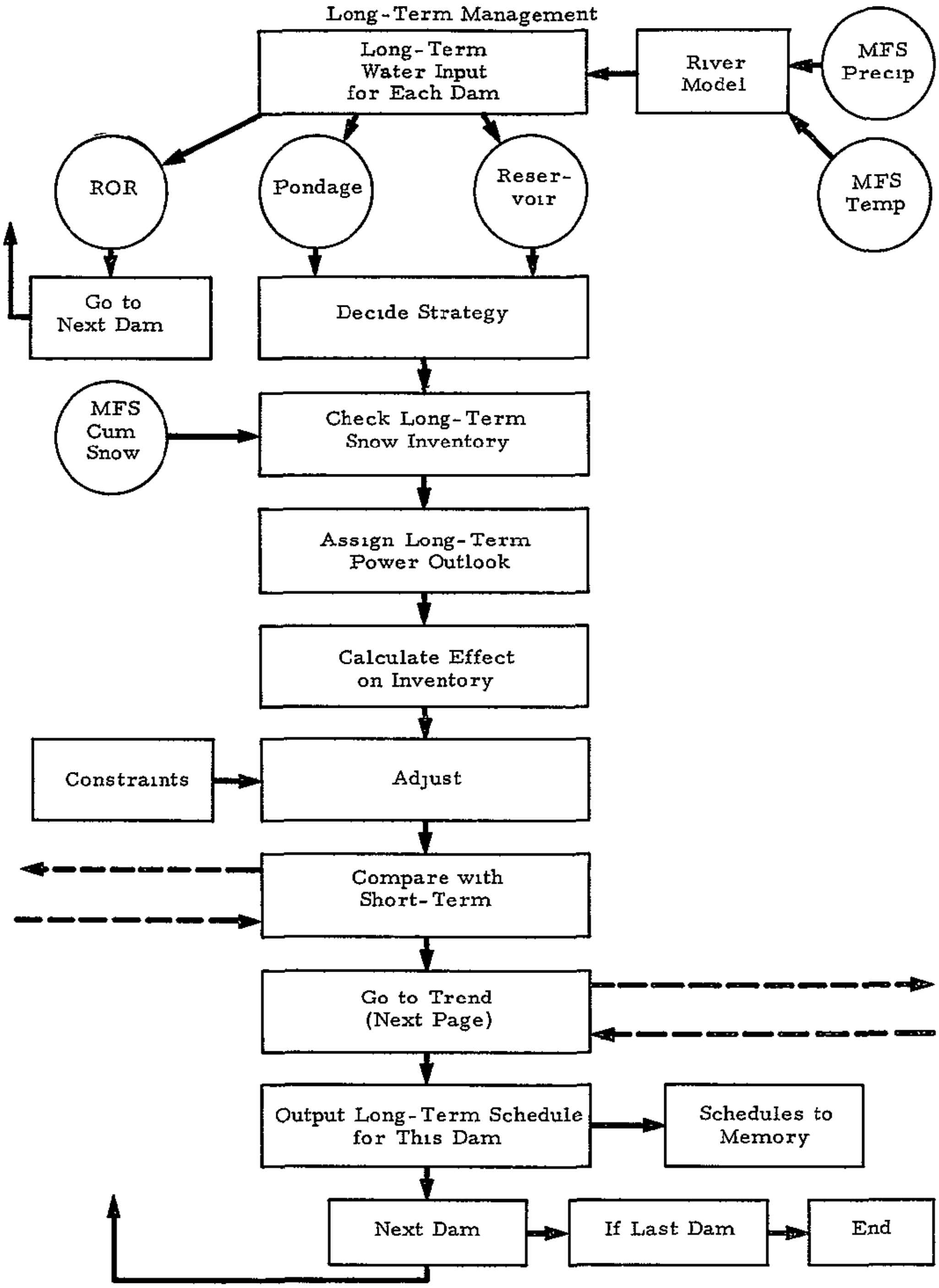


EXHIBIT II-29 (Continued)

Subroutine for Generation Trend (Long-Term Management)

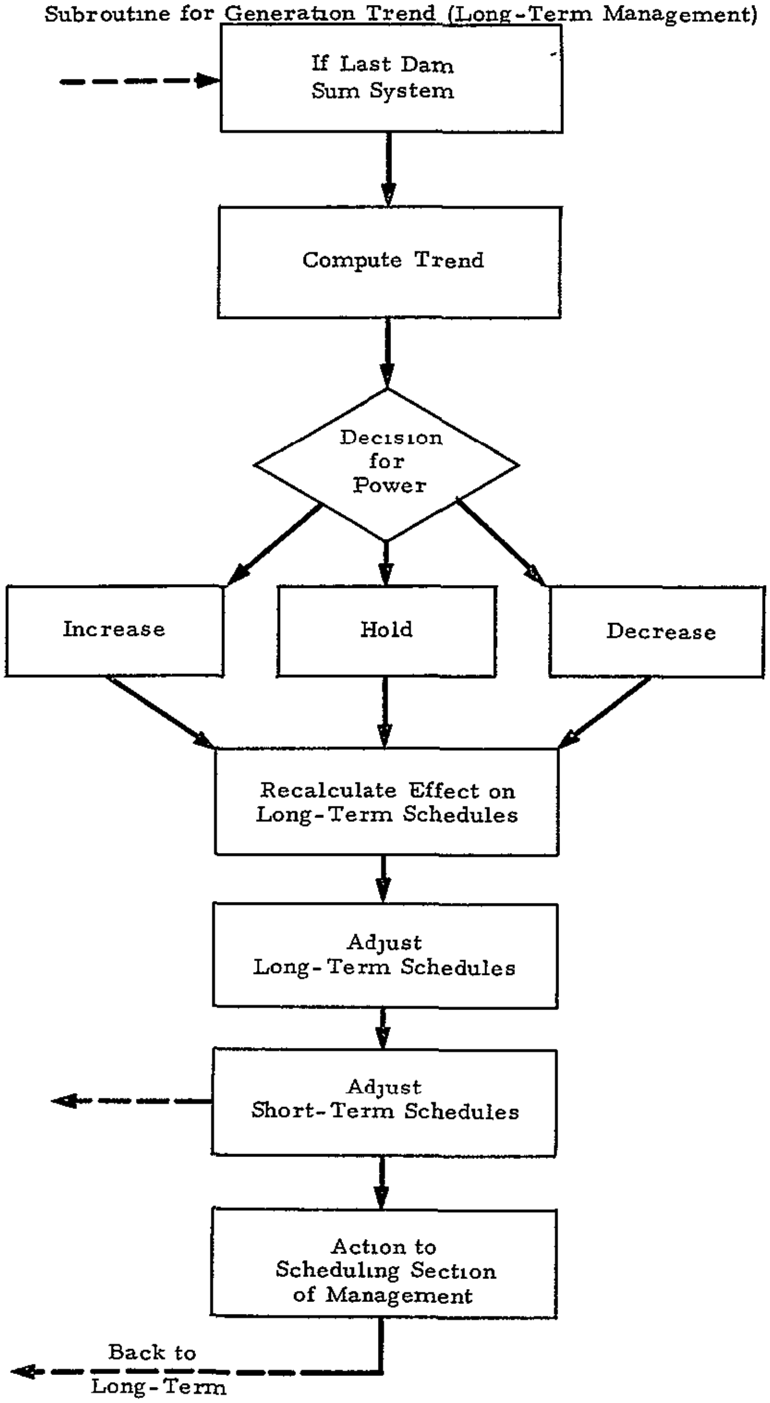


EXHIBIT II-29 (Continued)

storage water and would lessen the amount of spill during refill. Short-term information will aid in releasing a smoother flow to the RORs downstream from the annual dams.

Finally, consider the cyclic dams, which are located near headwaters and hence have low flow rates. Hydrogenerating capacity is greater than inflow under some water conditions The water release strategy is important, because the value of the water released by the cyclic dams is high if it is utilized by all series-connected dams below the cyclics Excluding evaporation and consumptive uses, release can be timed to supplement the power load of the whole Columbia River system, rather than to support a local load. Forecasting tells how much water can be released from storage for hydrogeneration and still assure refilling for the next water year. As more storage becomes available (with the Canadian treaty) some presently annual dams will become cyclic. Thus, forecasting information for the optimum management of cyclic dams will become more important in the next 20 years

Clearly then, for each class of dam there are benefits to be gained from a management system that is responsive to long-term and short-term inventory and demand forecasts

The benefit areas identified and established are

- Reduction in hedge
- Improvements in drawdown strategy
- Interreservoir coordination
- Improvements in head efficiency

Current operations in each of these areas and potential benefits from operation under an improved information system are described in the following sections

a. Reduction of Hedge

At present, the first determination of total seasonal runoff is made in January, and this estimate is subsequently refined on the basis of actual inflows through the season until April. At that time major melts occur and the snow inventory is released as water.

Briefly, the method used is one of indexing a few snow stations in selected basins and using historical correlations to predict seasonal

stream flow Owing to the small number of observations for any year, the correlation between the sum of the sample stations' inventory and the annual regional stream flow is quite rough After years of using and refining this technique, a standard error has been developed.

Since there is a contractual requirement to refill reservoirs by the end of the water year to a 95 percent confidence level, this error is used to reduce the forecasted inflow Thus, forecasts will deliberately underestimate stream flow and almost guarantee that spill will accompany refilling. The volume of water that this error represents is known as the "hedge" and represents a compromise between the requirements of the Corps of Engineers Flood Control Strategy and BPA's power management system The value of this hedge varies from year to year with forecasted stream flow and decreases monthly as better subsequent forecasts are made The residual on April 1 is the model error, the error at January 1 includes forecast as well as model error

If better forecasting techniques are used, both the model and forecast error can be eliminated Since the forecasting error is determined mainly by the lack of sampling, synoptic observation and measurement could almost eliminate the forecasting error The model error can also be eliminated by observation and measurement of the inputs to the subbasin model and by a better understanding of subbasin routing and timing

Currently, BPA is unable to use the hedge in cycle reservoirs efficiently In general, to avoid spill of the hedged volume of inflow, it must be utilized at a period of time when it will have maximum value This occurs when all dams below the cyclicals can utilize the volume and will not spill it If the hedge could be determined prior to January 1, then additional hydrogeneration could be produced at the optimum time to respond to maximum power load requirements

Thus, at best, the hedge represents a part of spill that occurs during refilling An analysis of typical hedge amounts is shown in

Appendix C The potential value for each hedge is calculated on the basis of perfect utilization.

For both models, the reduction of hedge has been evaluated in terms of additional power and revenue from additional power saved. Calculations of benefits are shown in Appendix C. In summary, the maximum average annual benefits are

Model	
Current 1968	Future 1975
$6 million	$26 million

Including the non-Federal installed capacity on the Columbia River system, average annual benefits are

Model	
Current 1968	Future 1975
$7.5 million (est.)	$29 million (est.)

b Improvements in Drawdown Strategy

There are periods of time during the water year when the hydrogenerating capability of the Columbia River system will be limited by the amount of installed capacity. Other times, operations will be limited by the amount of water available for hydrogeneration. That period of time that the system is water-limited--i.e., when outflow required for power generation is greater than inflow--is known as the critical period.

The Columbia River system characteristically has a great annual flow due to runoff of water held as snow and ice during the winter and released to the river after melt in spring and summer. This has led to a critical period of 7 to 9 months when the stream flow is low and must be augmented by releases from storage. Since the spring and summer runoff is great, almost all reservoirs can be refilled during the months of runoff. When the runoff starts, the reservoirs are being refilled, and maximum hydrogeneration can be effected. The problem is to use storage water during drawdown in the most efficient manner and replace it during the refill-hold phase with the minimum detriment to hydrogeneration

Power sales of two types are made in the Pacific Northwest The first is the sale of "firm" power, which guarantees the purchaser the delivery of so many units of power per unit of time. The other is the sale of "secondary" or "as available" power, which the purchaser cannot claim except at the discretion of the power producer.

A series of operating guides have been developed for dam management. These are in the form of "rule curves" for individual reservoirs. These curves are built around the 20th wettest (i.e., an exceptionally low runoff) year, and specify for each month during the water year what the minimum reservoir height (water in storage) must be. This is adhered to so that firm power obligation is assured of being met from month to month during the critical period. Exhibit II-30 shows the rule curves for three reservoir dams, and Exhibit II-31 shows historical operations typical of rule curve operated power dams.

Current policy and operation are fixed by means of the PNW Coordination Agreement. Briefly, all hydrogenerators satisfy their contracted loads and try to maximize the sales and/or export of secondary power. In wet years, much secondary power will be generated. The method of operation is load estimation, hydroresource shaping for load, and rule curve operation during each contract year

The benefit estimation, which appears in Appendix C, is based on optimum drawdown for the largest reservoir dams of the system Benefits accruing to these dams were extrapolated to the rest of the model The percentage of improvement is held constant for both time frames, the present and the future 1970's

The shape of the drawdown and refill curve is tempered by many variables Of note are

- The head efficiency evaluated during drawdown
- The restoration or speed of refill
- The amount of protection necessary for flood control
- The physical constants of storage, outflow (sluice and turbine capacity), and conditions below each dam
- The required minimum use of storage under the worst inflow conditions of record

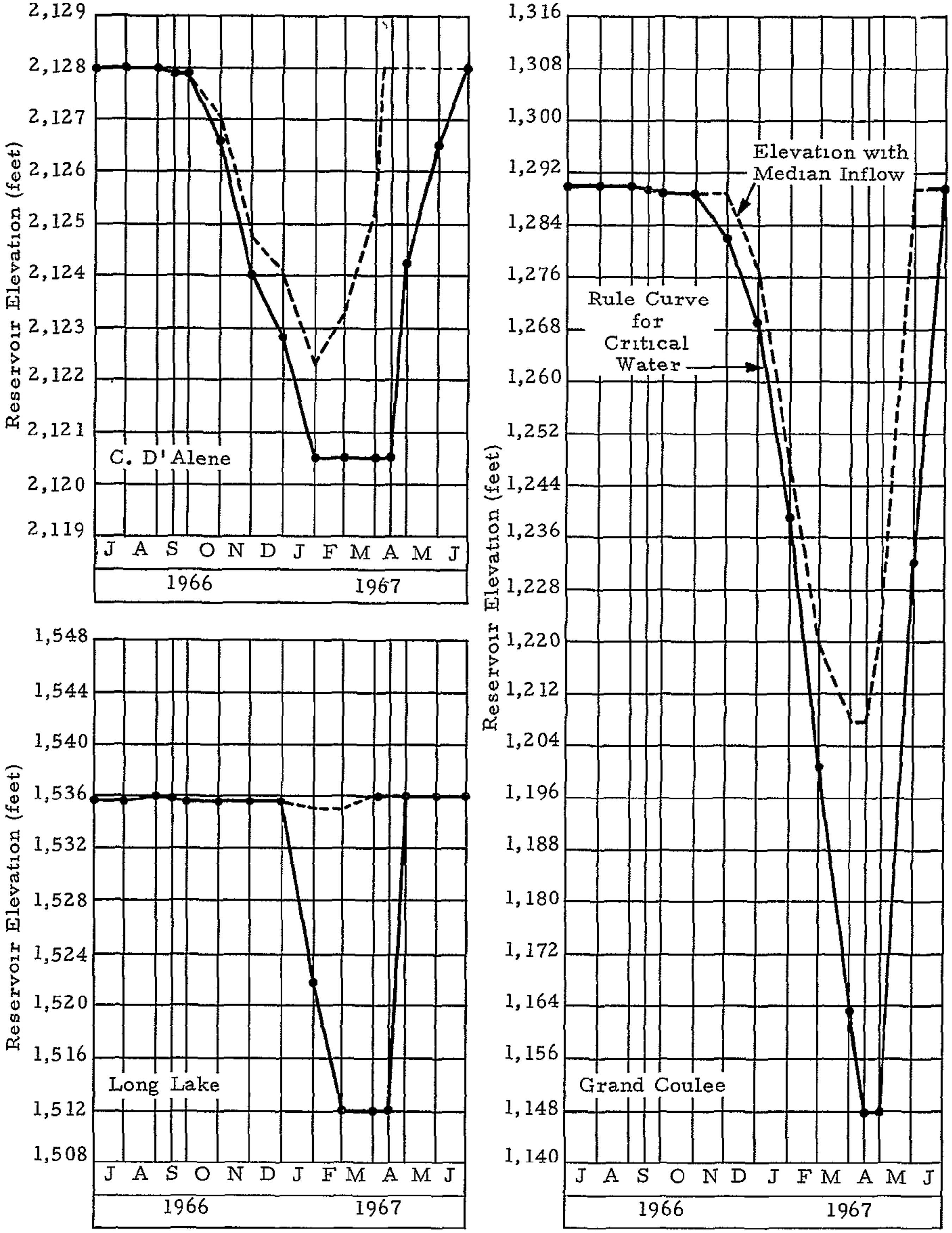
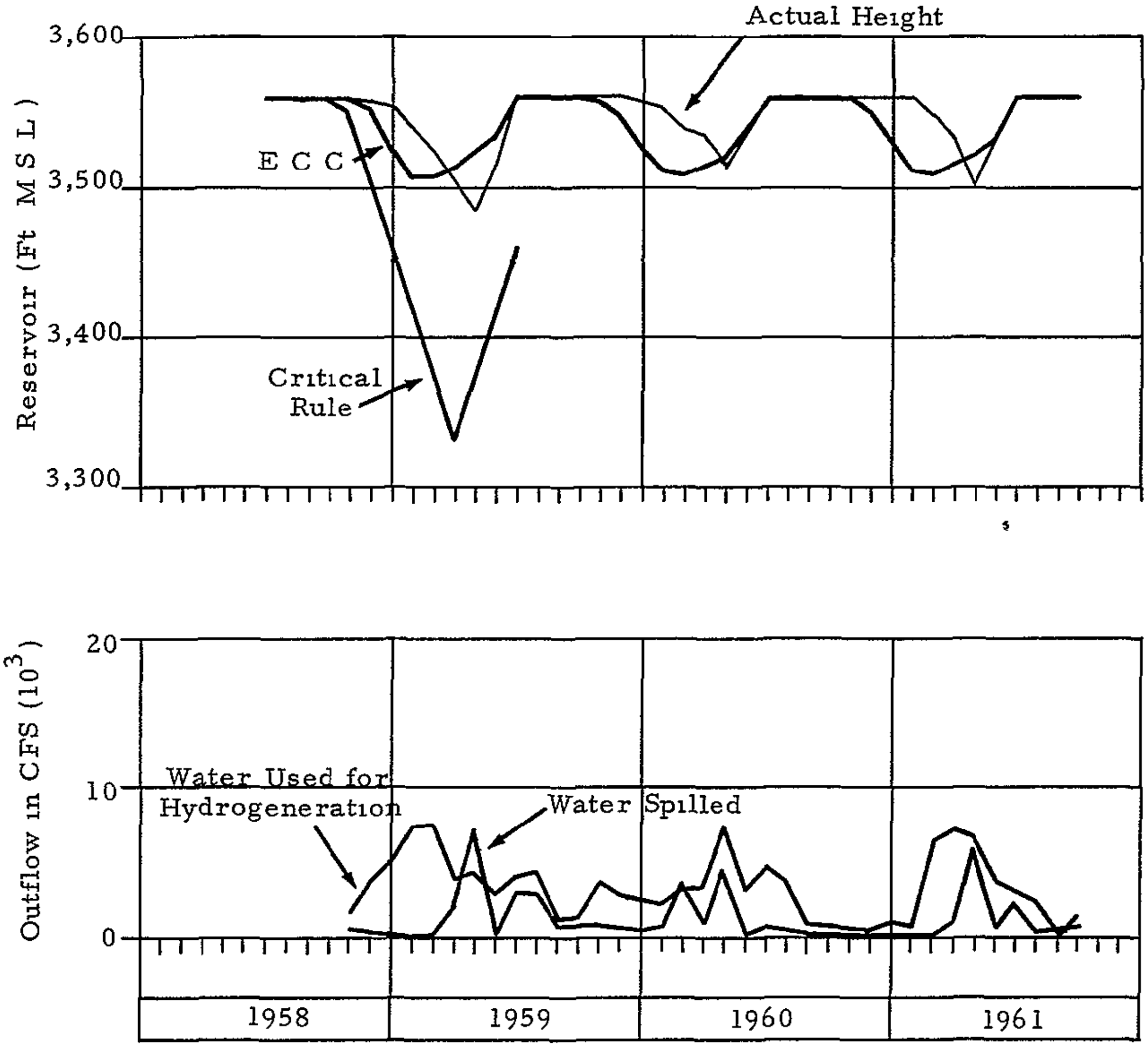
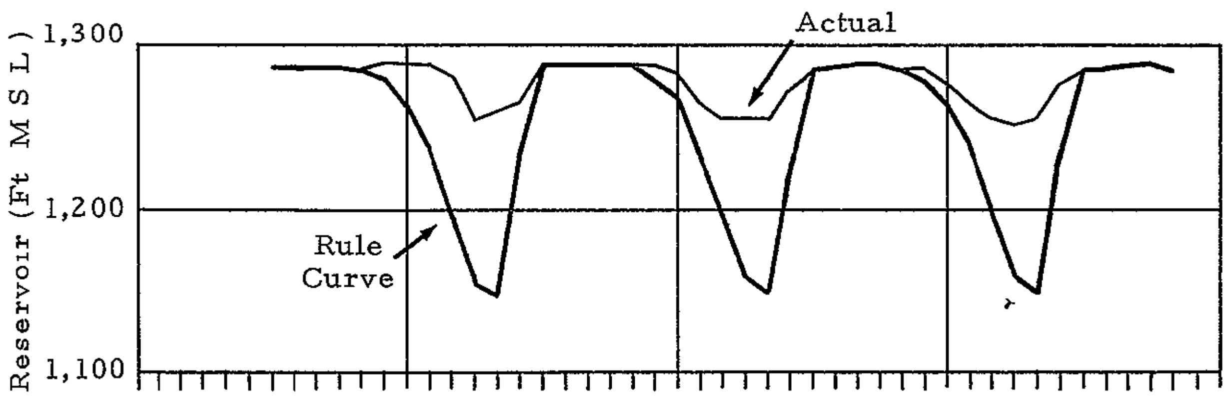


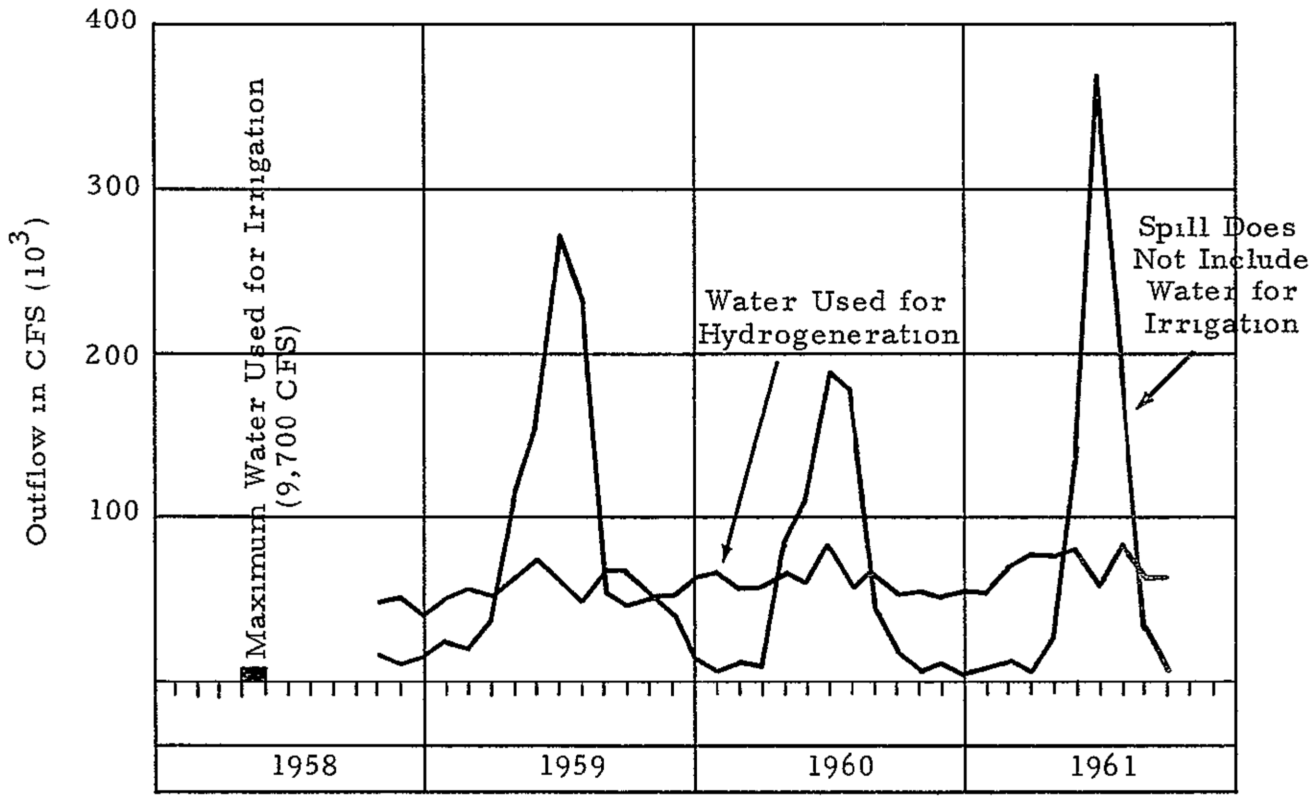
EXHIBIT II-30 RULE CURVES FOR THREE RESERVOIR DAMS



HUNGRY HORSE DAM

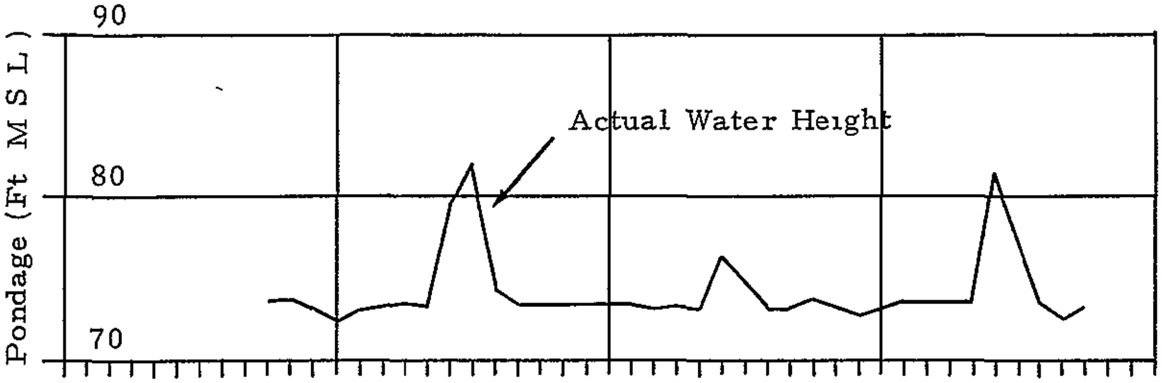
EXHIBIT II-31 OPERATION OF THREE DAMS

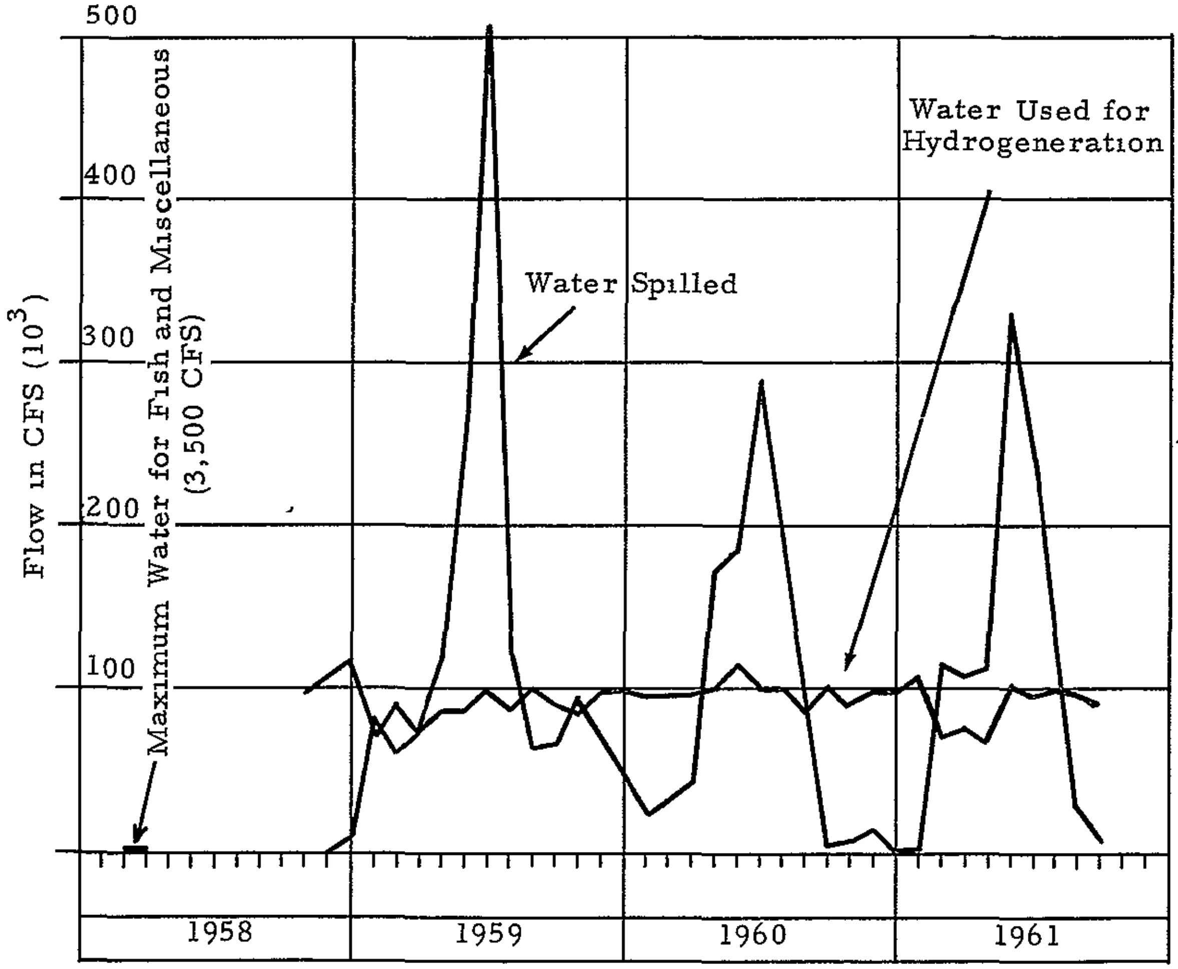




GRAND COULEE DAM

EXHIBIT II-31 (Continued)





BONNEVILLE DAM

EXHIBIT II-31 (Continued)

In general, the final optimization of hydrogeneration was a weighted solution of the "river equation" with simplifications and limiting assumptions. This analysis is only an approximation useful for showing the sensitivity of additional benefits Long- and short-term inflow were treated deterministically through synoptic coverage of the basin associated with improved inflow forecasting. Of the benefit areas, drawdown and refill strategy is the most tenuous benefit and the hardest to demonstrate without exercising the entire system rather than a simplified model. Total benefits with improved drawdown management in increased revenue alone are.

Model		
Current 1968	Future 1975	System
$ 7.5 million	$16.1 million	for the Federal system
$15.7 million	$33 8 million	for the Federal and non-Federal systems combined

c. Interreservoir Coordination

Of the total input to Bonneville, about 60 percent is from Grand Coulee, 30 percent is from the Upper Snake River, and 10 percent is from interreservoir flows These interreservoir flows are small rivers and streams of which over half are gaged and enter the main stream between ROR's. The other half (5 percent of the input to Bonneville) are ungaged because of inaccessibility or cost. With synoptic observation it would be possible to reduce the uncertainty regarding the magnitude of these ungaged flows In terms of maintaining as constant a level as possible on the main stem, knowledge and prediction of ungaged flows could prevent spill or loss of head that would otherwise occur from lack of knowledge

For the purpose of analysis, one can consider the problem of river management where a portion of flow is unknown and hence subject to spill. The effect of ungaged inflow is magnified if compensatory releases are made from Grand Coulee to make up for lower than expected interflows. This release, in turn, allows the water to go through the RORs at times that do not coincide with load requirements This

compensatory release must be made from Grand Coulee When this is done, the increased conversion factor of Chief Joseph must be added to the calculation of the conversion factors for the RORs below Chief Joseph

The effect and magnitude of the ungaged local flow now and in the 1970's will differ only by the addition of another dam on the main stream, John Day, which will be operational by 1970 At present, a conversion factor of 6 5 KW/cfs has been assumed for this dam in the future model The effect of ungaged inflow will not be significantly changed by the provisions for Canadian storage and additional installed capacity on the main stem

Indirectly, the problem of interflows affects the drawdown strategy of the reservoir dams higher up on the main stream By controlling interflows unnecessary releases from the reservoirs during the critical period could be avoided This would increase the total energy generated during the critical period for these reservoir dams

An analysis of the local ungaged inflows and of the benefits accruing from satellite information and forecast are included in the Appendix C

In summary, using both the present and future river models, the benefits from increased hydrogeneration of RORs alone are

Model	
Current 1968	Future 1975
\$3 8 million	\$4 7 million

Extrapolating to the Pacific Northwest Area as a whole at 2 1 times BPA benefits, the total Northwest Area benefits are

Model	
Current 1968	Future 1975
\$7 9 million	\$9 8 million

d Potential Improvements in Head Efficiency

Head is the reservoir height or the difference between forebay elevation and tailgate elevation In most reservoir dams it is not uncommon that the conversion factor for a full reservoir is

twice that for the same dam with a nearly empty reservoir A CFS of water at a full reservoir can produce 24KW, while the same CFS behind the same reservoir when nearly empty may only produce 12KW

It is immediately apparent that for maximum utilization of water for hydrogeneration, all reservoirs should be as full as possible for as long as possible Power and flood control requirements make it necessary that water be taken from storage through the year As water is taken from storage, the conversion factor decreases For each generator there is a maximum flow limit for each turbine Thus the maximum amount of power that can be produced is limited by maximum turbine discharge in CFS Maximum power capability equals maximum turbine discharge times conversion factor at reservoir height

For example, in April, the maximum capacity of Grand Coulee would be

Turbine discharge 95,000 CFS

Conversion Factor at elevation 1, 208 = 12 5 KW/CFS

Output (95,000) x (12 5) = 1,187 MW

The generators are rated under load at 1,977 MW At times when the reservoir is full, as in September, we can easily generate at the rated load

Turbine discharge set for 78,000 CFS

Conversion factor at elevation 1,290 feet = 25 35 KW/CFS

Output (78,000) x (25 37) = 1,978 MW This is the limit of generation at Grand Coulee

The difference between full and empty reservoir then is 791 MW Thus in April with an empty reservoir, the maximum level of hydrogeneration cannot be greater than 60 percent of the installed capacity Inflow is limited by turbine design, and the flow conversion factor is the result of a low head or reservoir level

Head efficiency is a function of the head over time In general, higher average levels of hydrogeneration will be obtained with higher average heads To maximize head during drawdown and refill requires that drawdown be deferred as long as possible and storage replaced as soon as possible during the refill-hold period If power demands during

the drawdown period are great, water taken from storage will reduce the head and the level of generation If demands are low, water will be conserved in storage with a resulting maintenance of generating efficiency A compromise is necessary, since flood control requirements demand a certain amount of reservoir space for flood decresting During average and wet years, lowering of the reservoirs for flood control requirements is necessary with a reduction of power from the loss of head In some cases a "forced outflow" is necessary to reserve the space for flood control

If a reservoir fails to refill, it will start the next drawdown season with a lower head, and a lower level of hydrogenerating efficiency Management that assures refilling of cyclic dams with a 95 percent confidence of fulfilling water demands and reduces the "hedge" will improve head efficiency

In general, head efficiency is a compromise between the desire for maximum hydrogeneration, power demands, and flood control requirements Head efficiency cannot be easily estimated without exercising the total system and calculating the reservoir level that determines head efficiency Insofar as additional information makes it possible to avoid early drawdown and slow refill to control flooding, head efficiency will be increased But, reducing the hedge will tend to reduce reservoir levels and thus decrease head efficiency More accurate interflow forecasts will hold the head on RORs at optimal levels On balance head efficiency should be improved, but the amount is difficult to estimate

e <u>Assumptions of Analysis</u>

Throughout the preceding analysis simplifying assumptions have been made Some of them have been explained In this section, several more are made explicit

It has been assumed that there will be an unlimited market for hydroelectric power in the Pacific Northwest This is not presently the case, however, it is inevitable that power requirements in the area in the near future will exceed the capabilities of the hydroelectric system Consequently, thermal, probably nuclear, power generation will be

introduced, furnishing up to 50 percent of the total power output in the Pacific Northwest by 1980 It has been estimated that the costs of thermal power will be about double those of hydroelectric power Thus, it will still be important to maximize the use of hydrogeneration

No hard or soft constraints are acknowledged for optimum drawdown of annual reservoir dams Optimum drawdown has been made for power purposes alone, subject only to the Corps of Engineers' refill requirements Minimum outflow, maximum change in outflow, emergency drafts, and minimum river height fluctuations have been disregarded, though their effect on present hydrogeneration is not minimal The rationale is that a better management system would lead to the relaxation of some of these constraints

The extrapolation of benefits from the U S Columbia River system (Federally operated) to the total hydro power of the Pacific Northwest (including both Federal and non-Federal) has been made on the basis of the ratio of non-Federal plus Federal installed capacity to Federal installed capacity This ratio is 2 1 1

2 Irrigation

Impact of a Satellite-Assisted System on the Present Irrigation Information System

The volume of water diverted for irrigation in the United States is over 300 million acre-feet per year and increasing at an annual rate of approximately 2.5 million acre-feet There are approximately 43 million acres of land under irrigation in the United States Almost all of this acreage is in the 18 western states More than 33 million acres were irrigated in 1959, and the value of crops raised on this irrigated acreage amounted to over 2 4 billion dollars The average grass crop value per irrigated acre served by the Bureau of Reclamation was over $200 in the year 1966

The areas in which benefits may be achieved are shown on Exhibit II-32 The inputs that will be affected by the satellite-assisted information system and the areas of improved results due to the better information are shown on Exhibit II-33

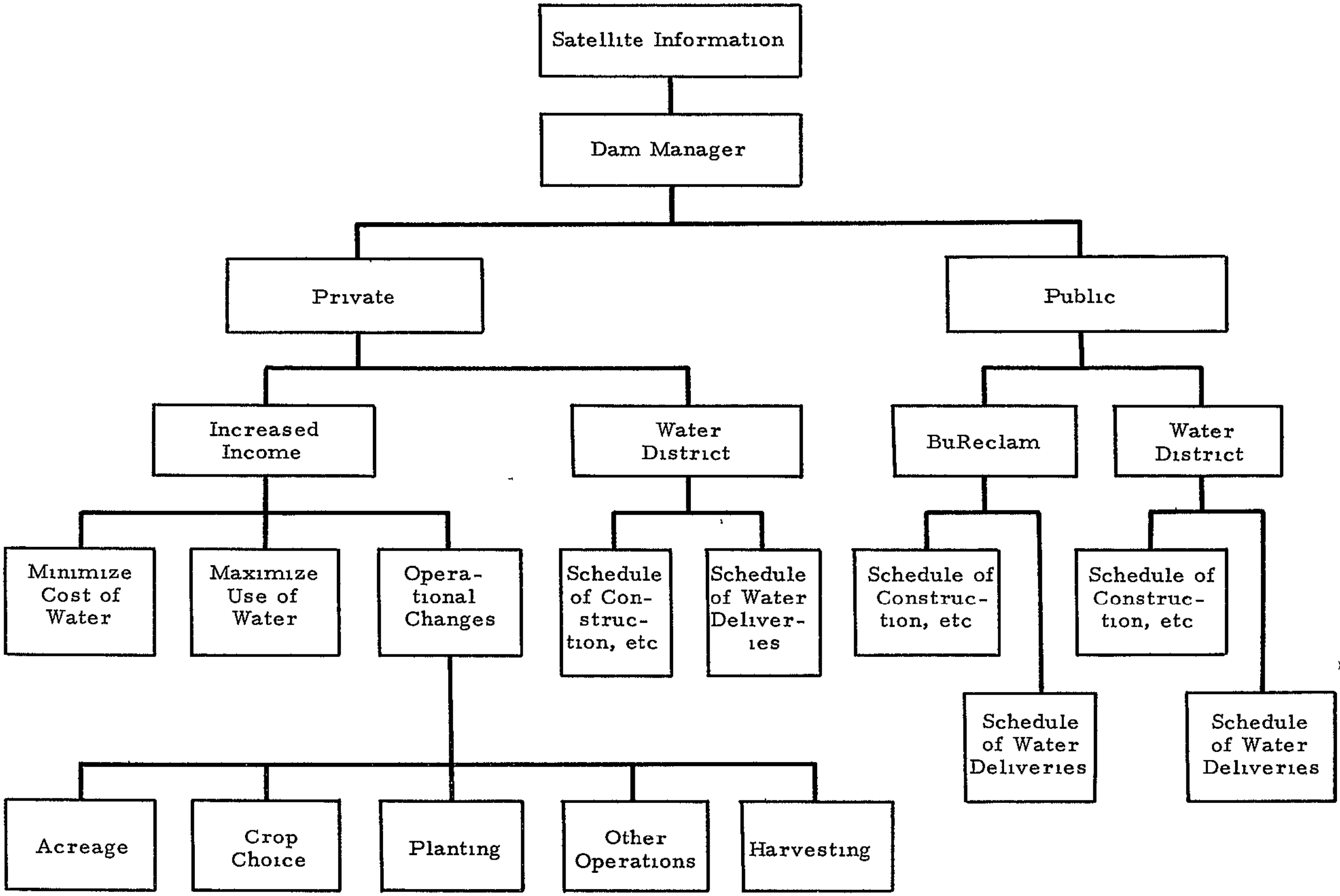


EXHIBIT II-32 HYDROLOGY INFORMATION FLOW FOR IRRIGATION

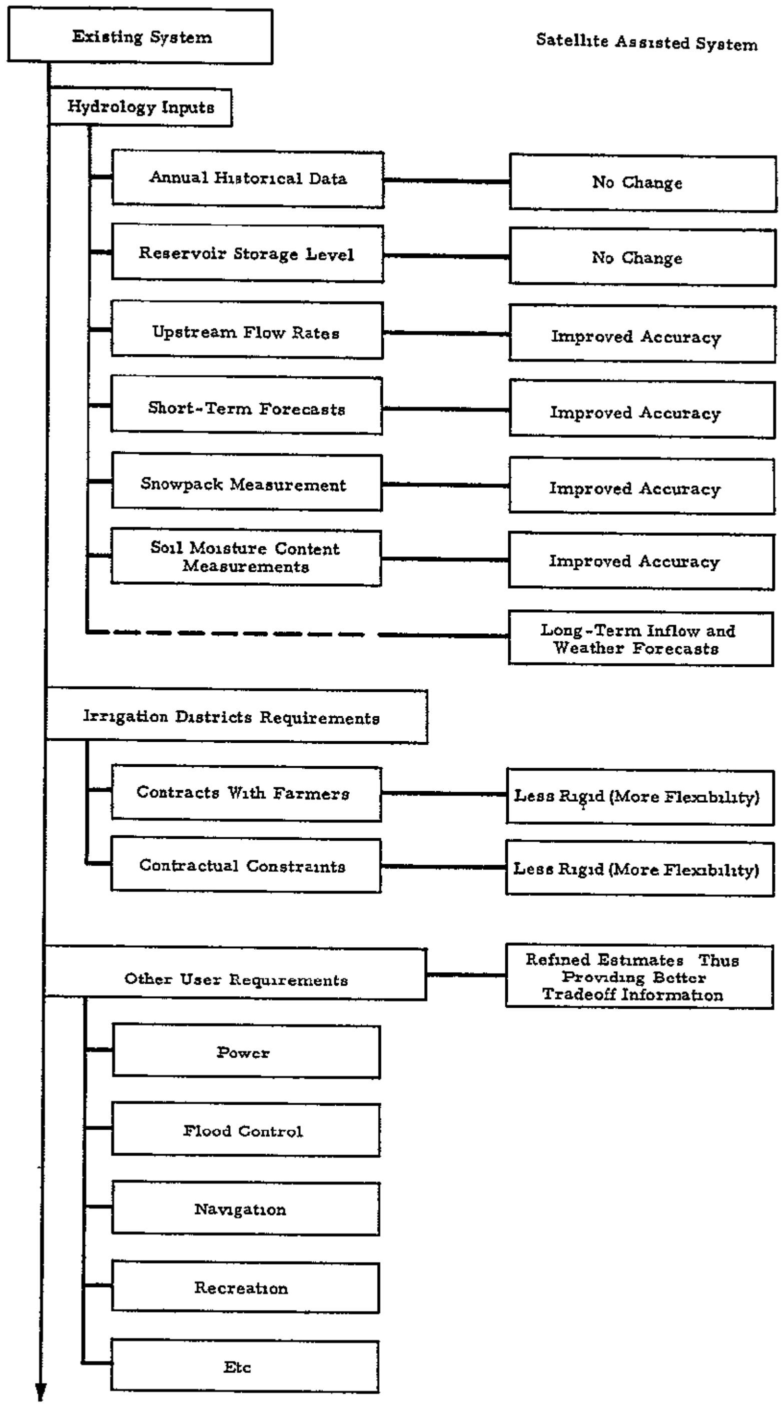


EXHIBIT II-33 IRRIGATION MODEL

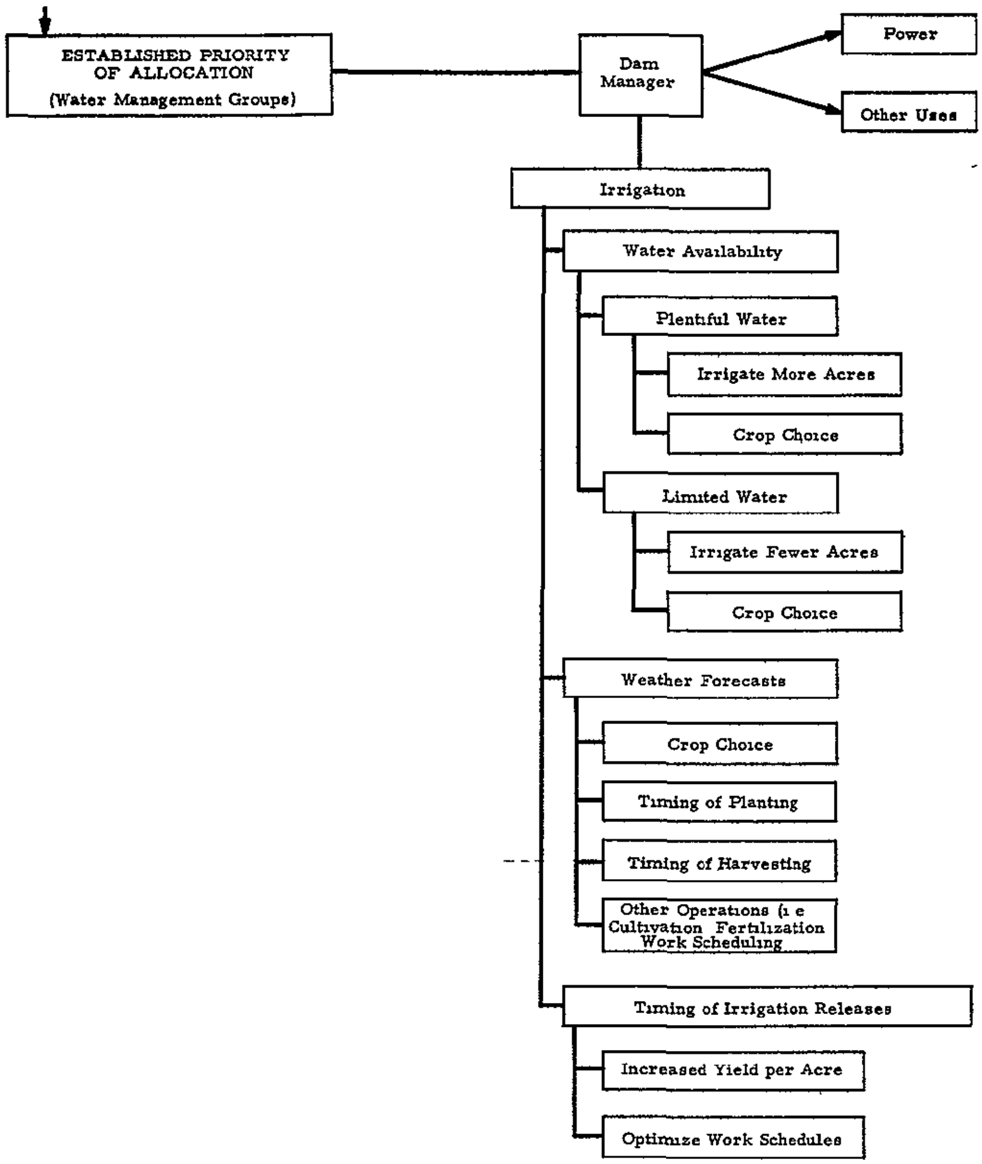


EXHIBIT II-33 (Continued)

It is expected that improved hydrologic information and the growing need for more efficient water utilization will lead to evolutionary easing of contractual constraints connected with water supply This in turn will lead to more flexibility during the course of the growing season in either releasing more water or, in some instances, withholding it Some of the kinds of constraints that might be affected include longstanding water rights, costs of water to the farmer, and ambiguous or contradictory provisions regarding the priority for different use classes The emphasis on water efficiency will intensify as the marginal cost of supplying the water approaches the marginal value in use

Refined estimates of forecasting will also provide better information for determining the tradeoff among uses of water for power generation, flood control, municipal and industrial applications, navigation, and recreation' Distribution of the water supply will then be made based on this information together with a priority of allocation established by the various water management groups Water is often used for power generation and then diverted for irrigation In such situations, there is no need for allocation between the two uses of the water, however, there is often a need for close coordination of scheduling to provide optimum use of water for both power generation and irrigation

Contained in the supporting Appendix is an analysis of the irrigation system in the Pacific Northwest, including benefits to be derived by power generation sales and pumping savings Benefits could be achieved in power generation revenues as a result of information that would permit the pumping of irrigation water into Banks Lake (a storage lake for irrigation water) in only the amounts needed for efficient irrigation of the project It is expected that sales of $1,250,000 could be obtained annually from sales of power generated by water that would otherwise be unnecessarily diverted for irrigation in the Columbia Basin project In addition, $660,000 could be saved annually by not pumping the additional water into Banks Lake

Farmers' decisions and operations as they relate to water supply are shown in Exhibit II-34 Better information prior to planting time will enable the farmer to make better judgments about the acreage and variety

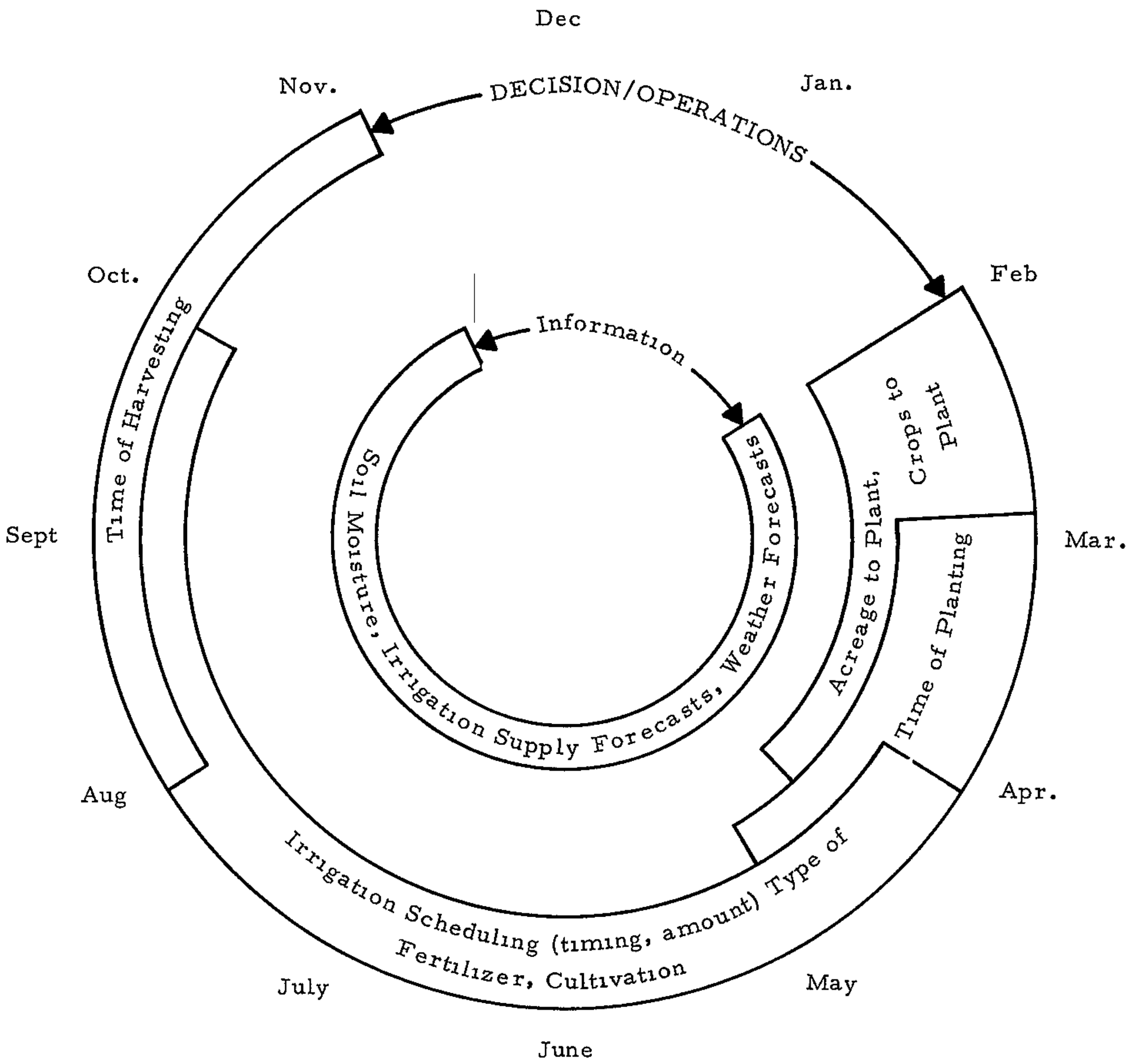


EXHIBIT II-34 FARMER RESPONSE TO WATER SUPPLY INFORMATION

of crops to be planted, Information on available water supply, estimates of prices for crops at time of harvest, availability of farm loans, labor supply, and crop rotation practices all affect the choice of crops that will be planted Crop planting and harvesting operations, cultivation, fertilization, and work scheduling, are all affected by water supply considerations

The various agricultural decisions farmers make depend on the information that is obtainable and relayed to them by dam managers, various state engineers' offices, and other private, State, and Federal organizations Farmers are also dependent on a combination of snow surveys and water supply bulletins, together with radio and television releases and information published in newspapers and farm journals Many times agricultural organizations and soil conservation districts release information directly

Snow surveys just prior to and during the critical melt period provide an assessment of the amount of water available for runoff This information is generally available to the farmer by February or early March These measurements are used in forecasting the amount of water to be available for the growing season

Farmers use forecast information in crop planning and in consequent actions taken throughout the growing season From the early part of March to mid-April, farmers decide the number of acres as well as the best choice of crop to plant, taking into consideration water supply forecasts for the coming growing season Better information concerning soil moisture content and future weather conditions to be expected would be of value to farmers in initial decisions regarding crop choices and planting time During the growing season, this same information is of value to farmers in scheduling irrigation, fertilization, and cultivation Toward the end of the growing season, improved weather forecasts (especially precipitation and temperature) affect farmers' decisions regarding the best times to harvest The timing of harvests may seriously affect scheduling of hired help and machinery and the market value of the harvested crops For example, heavy, unforeseen rain fell in southern Idaho in August 1968, causing considerable damage to garden and

grain crops near harvest time Better forecasting would have enabled farmers to have scheduled harvesting operations at an optimum time

The value of satellite-assisted information system to irrigation can be measured in terms of its contribution to reducing the forecast error Appendix C shows the potential irrigation benefits over the 20-year period by reducing forecast error Irrigation benefits come from the uncertainty of the water supply A normal water year in the model compares with a perfect forecast The annual error over the past 50 years has averaged approximately 20 percent. According to the hydrological and meteorological information found elsewhere in this report, it is anticipated that the forecast error can be reduced to 5 percent, in other words, there would be a 95-percent accuracy in forecasting We can therefore expect $4 million in benefits in an area the size of the Columbia River Basin project (over 500,000 acres) for 1970, and with increased irrigated acreage, we can expect benefits to increase to over $9 million in 1990 Benefits for the Pacific Northwest would be $62 million in 1970 and $79 million in 1990 Total benefits for the United States would exceed $350 million in 1970 and nearly $500 million in 1990

In the field of agricultural economics, research is continuing on the consumptive use of individual crops in varying geographical and climatological areas Overirrigation can reduce crop yield as can underirrigation Therefore, the amount and timing of water supply to crops is important in attempting to optimize the yield for each crop grown Much water is wasted due to deep percolation, the passing of water through the soil beyond reach of the crop roots The value of information that helps to identify soil moisture content and to forecast precipitation and runoff can readily be seen With such information, irrigation releases can be scheduled around existing soil moisture conditions, precipitation forecasts, and water availability from runoff Thus, both an increase in yield due to more efficient irrigation and a savings of irrigation water can be realized

3 Flood Control

Columbia Falls, Montana, and Vancouver, Washington, basins were used as sample cases for the study of economic benefits from improved flood control operations Benefits from flood control are calculated on the assumption that the satellite-assisted information system will provide information in time to enable reduction of river levels at maximum flood stage by two feet This assumption is in keeping with the expected improvements in runoff forecast accuracy brought about by the satellite-assisted information system It is also assumed that the whole system is operated with the Canadian storage and the Libby Project, scheduled for completion in the early 1970's

Exhibits II-35 and II-36 indicate the various areas of flood control benefits and the flood warning time required for appropriate action to protect human life and the several classes of property It is estimated that a reduction of river level by two feet in the Columbia River Basin will result in an average annual saving of $10 million, as computed in Exhibit II-37 It is recognized that there are numerous low areas where it is not economically feasible to provide protection by levees Land enhancement can be almost the entire benefit within such areas, and the feasibility of their protection depends primarily on reduction of flood stages

Indirect savings due to the protection of business activity which would otherwise be disrupted by floods are shown in Exhibit II-38, which was compiled in the following way Average annual loss in Columbia River Basin is $12 million Total indirect loss (column 4, Exhibit II-38) can be computed by multiplying the direct loss (column 2 = $12m x column 1) in each category by the corresponding indirect loss factor (column 3) Column 5 relates to the average saving of 75 percent in each category and the total indirect saving has been worked out to $8 5 million These benefit figures appear again in Exhibits II-49 and II-54 as part of the total water management benefits.

To measure the amount of snow on the watersheds and thereby foretell the flow of rivers months later, snow surveys are undertaken in the mountains Records show that precipitation (and runoff) may depart markedly from the mean in any year

3

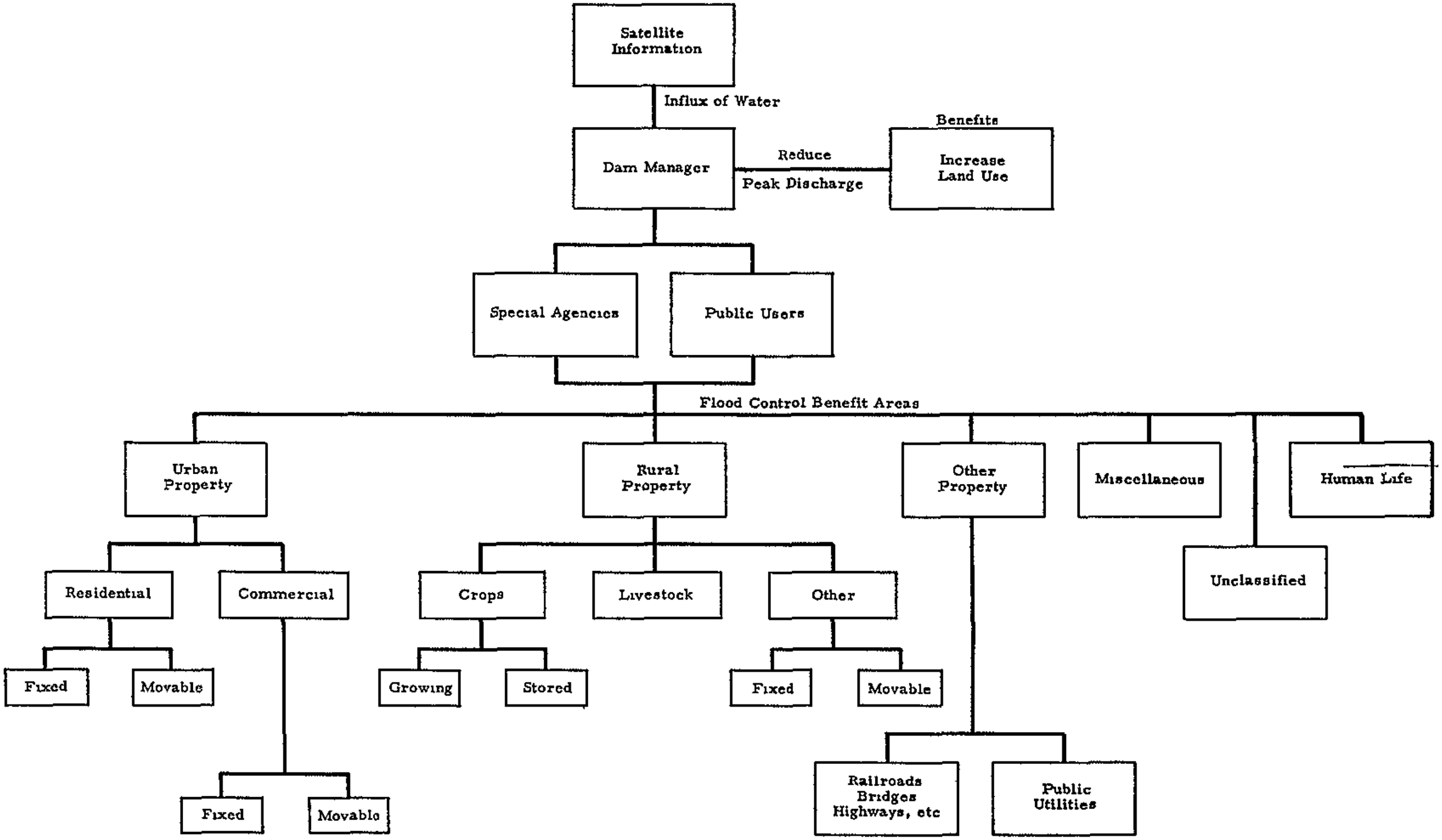


EXHIBIT II-35 FLOOD CONTROL BENEFIT AREAS

EXHIBIT II-36 FLOOD CONTROL WARNING TIMES AND PROTECTIVE ACTIONS

Class	Example	Min Warning Time	Protective Action	Class	Example	Min Warning Time	Protective Action
1. Residential Property, Fixed	grounds trees shrubbery fences, walks dwellings garages	2 days	sandbags	6 Rural Property	stored crop	24 hours	evacuate
2. Commercial Property Fixed	land buildings mines wells	2 days	sandbags	7 Rural Property	livestock		
3. Residential Property, Movable	furnishings equipment utilities personal effects vehicles	12 hours	evacuation	8. Other Prop	RR's bridges, highways, etc.	1 week	sandbags
4. Commercial Property, Movable	equipment supplies stock utility plant	24 hours	evacuation	9. Public Utilities	public land playground parks, roads water supplies waterways, etc.	3 days	sandbags
5 Growing Crop	cost of re-planting building equipment supplies land through swath and disposition	1 week	levees sandbags	10 Lives Lost			

EXHIBIT II-37 POTENTIAL AVERAGE DIRECT ANNUAL SAVINGS FROM FLOOD CONTROL-COLUMBIA RIVER BASIN

Average Annual Direct Loss in Columbia River Basin = $12, 000, 000

	Residential		Commercial						
	Fixed Property	Movable Property	Fixed	Movable	Crops	Rural Property	Other Property	Public Utility	Total
Percentage Loss	28	2	10	1	28	5	24	2	--
Average Annual Direct Loss	3,360,000	240,000	1,200,000	12,000	3,360,000	600,000	2,880,000	240,000	12, 000, 000
Percentage Saving	84	82	83	83	85	87	82	83	--
Average Annual Saving	2,820,000	201,000	996,000	10,200	2,856,000	522,000	2,360,000	199,000	10, 000, 000

TOTAL SAVING (AVERAGE) = $10,000,000

EXHIBIT II-38 POTENTIAL INDIRECT SAVINGS FROM FLOOD CONTROL - COLUMBIA RIVER BASIN

Category of Damages	% Loss	$ Loss Direct	Indirect Loss Factor	$ Loss Indirect	75% Saving
Industrial, including utilities	2	240,000	1.2	288,000	216,000
Urban--commercial, residential and public	40	4,800,000	1.5	7,200,000	5,400,000
Rural	32	3,840,000	0 2	768,000	576,000
Highways, railways	26	3,120,00	1.0	8,568,000	6,000,000
Total		12,000,000	9	11,376,000	8,532,000

75% indirect savings due to reduction in River Stage = $8 5 million

TOTAL SAVING Direct and Indirect

(Per Annum) = $10,000,000 + $8,500,000

= $18,500,000

The problem in forecasting the seasonal runoff which could result in flooding is that of climatic departures from the mean during the runoff season Cold or warm and wet or dry spring weather affects the rapidity and volume of snowmelt and so affects the accuracy of the forecast Such climatic departures for 30 to 90 days in advance cannot currently be predicted with dependable accuracy Snow survey forecasters in the upper Columbia River Basin have been using the 30-day outlook of the U S Weather Bureau to calculate runoff forecasts

Runoff forecasts now available for consideration and use by managers and water users are of four types

- Forecasts of volume for the annual runoff - These are based largely upon analysis of rainfall records mostly of lower elevations
- Forecasts of volume for the seasonal runoff - These forecasts for the Western States are based chiefly on snow surveys and partly on related weather data The volume forecasts are usually for April-September
- Forecasts of approximate dates of streamflow recession to any given rate of flow
- Forecasts of potentially high peaks of flow - These forecasts are useful in advance planning for control of possibly dangerous flood peaks

River and flood forecasting (see Exhibit II-39) provides certain hydrologic information required by others for water inventory, water resources management, and minimum flow control

It is expected that a satellite-assisted information system will be such a medium for the following reasons

- Data can be acquired at an optimal time.
- The large areas seen in single observations enable interpreters to assess situations affected by certain large-scale parameters, e g , snow cover and flooded areas Better decisions will be possible regarding the collection of ground information

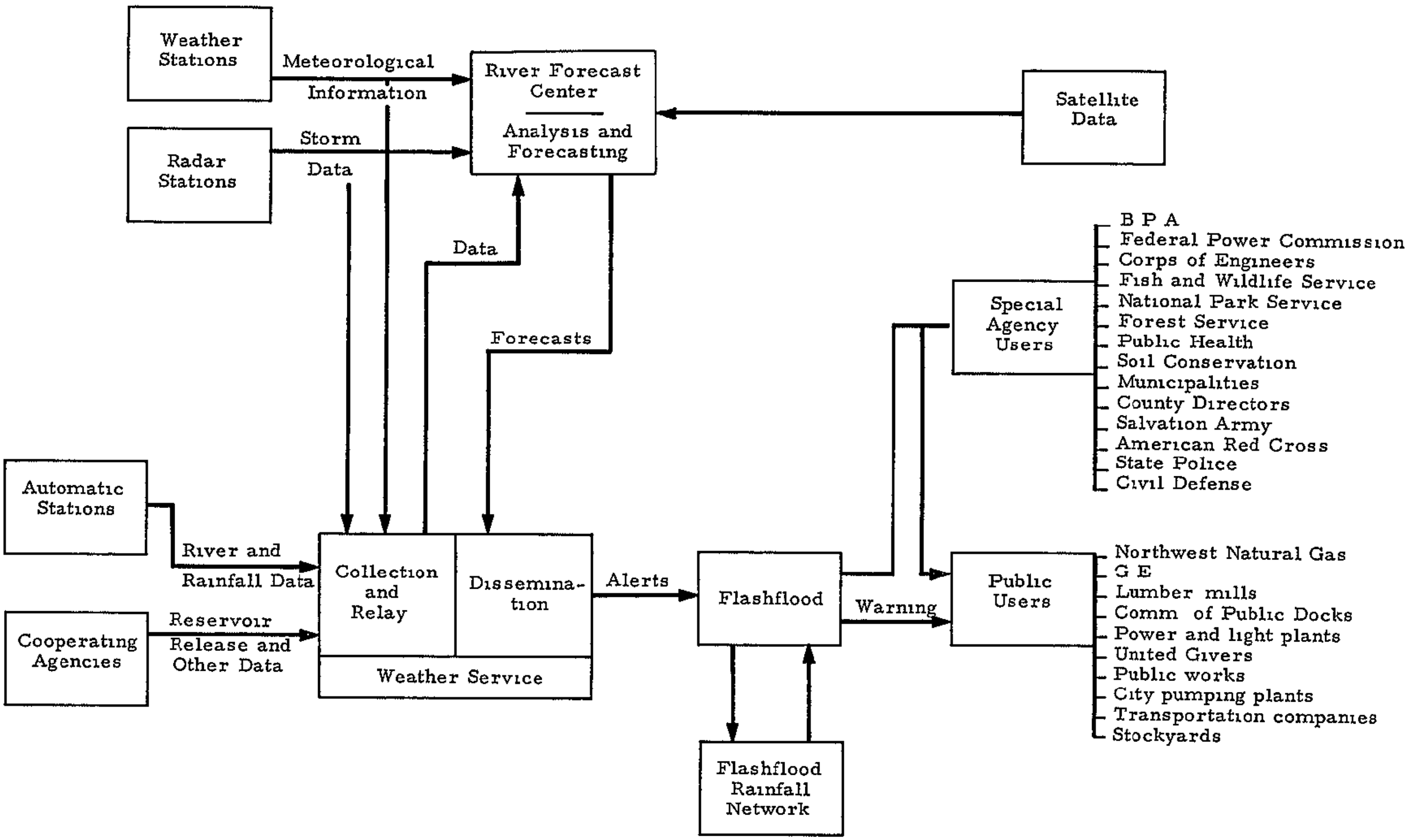


EXHIBIT II-39 PROPOSED RIVER AND FLOOD FORECAST OPERATIONS CHART

- Repetitive coverage and consistent coverage give the kind of data most useful in hydrologic studies.
- The speed of processing accumulated data will be greater than processing by present methods.
- Data can be correlated quickly and communicated quickly to areas where they can be most useful.

Particular observations most useful for flood control include precipitation of high intensity over wide areas, rain on snow, rain on frozen or saturated grounds and patterns of increasing air and ground temperatures anticipating rapid melt of both low and high-lying snow. The flood control manager needs assurance that seasonal peaks can be anticipated by 5 to 10 days, given routing and prediction lead times envisaged in the satellite-assisted system. He also needs the assurance that short-term peaks will not go undetected. With these assurances, and his ability to release water in an emergency situation, the power of manager will be able to hold reservoirs at a higher level than is now the case

4. <u>Navigation</u>

It would appear that better information might be used to manage the Columbia River so that stream flows are higher and steadier, but review of the recent developments in the Pacific Northwest shows that there are likely to be only negligible benefits to navigation from the satellite-assisted information system. Due to recent construction there is now a 14-foot channel on the greater part of the Columbia and Snake Rivers. The Inland Waterway Association, a shipping and barge group, is on record to the effect that a 14-foot channel is adequate. Few river boats have ever been developed that could utilize more depth, and all lock sills have been built for 14-foot boats. Furthermore, assuming that the Ben Franklin Dam is built by 1973, only 15 miles of moving water channel will remain on the designated navigation system on the Columbia

Although construction in the Pacific Northwest has nullified potential navigation benefits from a satellite-assisted information system at this time, had such a system been in operation in the early sixties,

it would have had a major impact. It is quite possible that in other less developed regions of the country, river navigation would be greatly aided by satellite derived information

5. Recreation

a. Methodology for Evaluating Recreation Benefits

The impact that satellites will have upon recreation must be evaulated by determining the increases in quality and quantity of recreation (see Exhibit II-40). The essential problem is to relate increased visitor rate and additional recreation appreciation. Various government agencies have long struggled with the problem and only recently have tended to accept a standard methodology.

There are five different techniques that are mentioned in the literature Due in some measure to the divergent nature of these five evaluation techniques, Government planners in 1964 moved to set a uniform method to quantify recreation benefits Outdoor recreation was becoming recognized as a valuable product of water development, and a standardized system was needed In U S Senate Document 97, Supplement No 1, entitled, "Evaluation Standards for Primary Outdoor Recreation Benefits," a schedule for determining monetary unit values is presented The range of values for a general type of recreation day is from $0 50 to $1 50, and the specific value to be assigned for a given day must be evaluated on a relative basis This dollar price is then multiplied by the estimated number of recreation days to determine the total recreation value

b Recreation Benefits in the Pacific Northwest

To evaluate recreation benefits in the Pacific Northwest, this study focused on the Grand Coulee Dam and the Franklin D Roosevelt Lake Roughly one-third of all recreation on the Columbia River occurs around this lake, and excellent utilization records have been kept

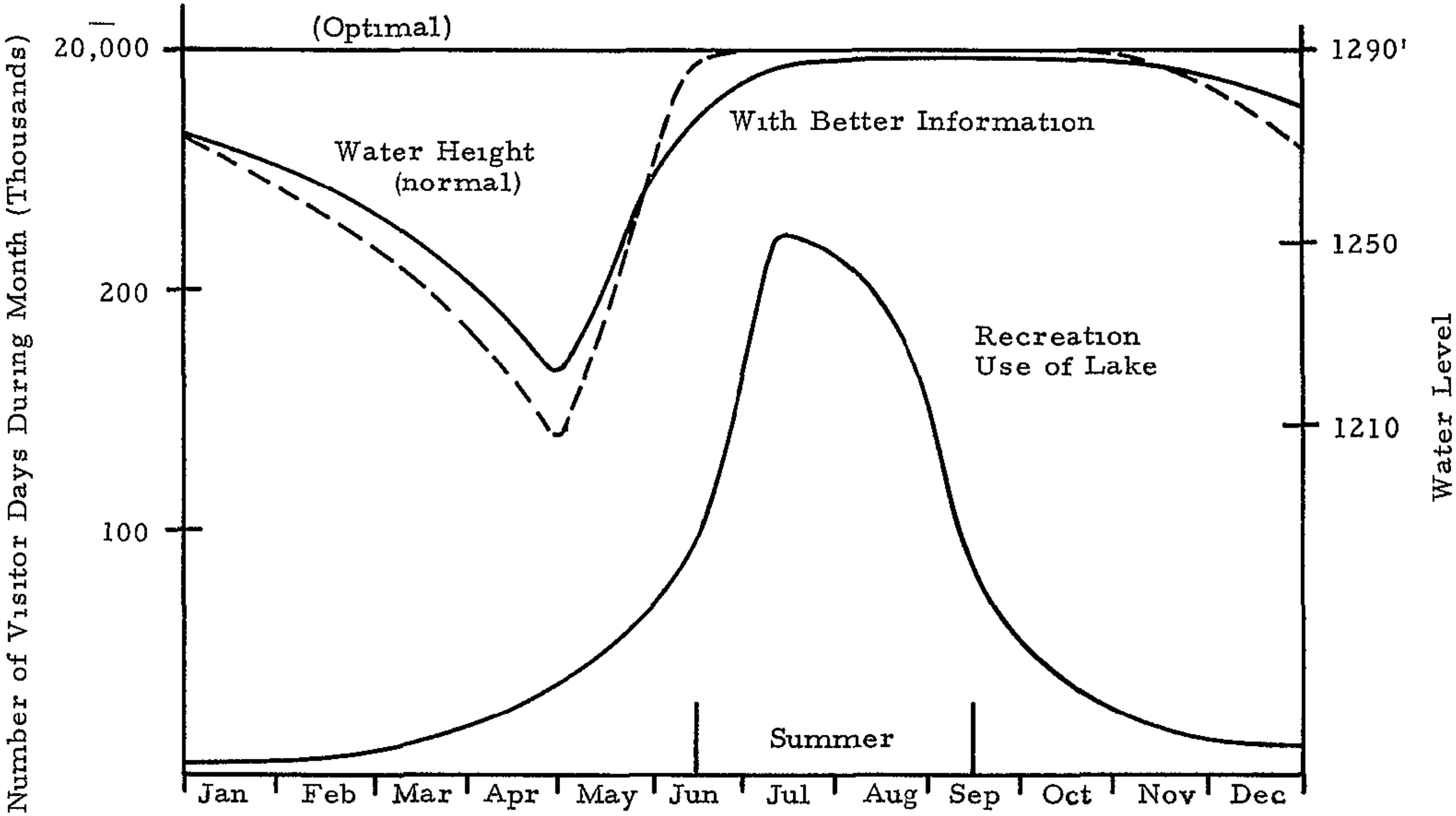


EXHIBIT II-40 GRAND COULEE RESERVOIR

Over two-thirds of all visitors to Grand Coulee come during the 3 summer months of June, July, and August. Exhibit II-40 shows the distribution of visitor days. The exhibit also shows how the reservoir level can be filled sooner and be kept filled as a result of the manager's knowledge that a flood safeguard was not necessary

In formulating the evaluation model that was used to quantify the benefits, the National Park Service of the Grand Coulee Dam was consulted They stated, "Our visitation is directly dependent upon two things--the weather and the water level" The Park Service was quite interested in anything that might improve conditions and was helpful in providing a feel for this dependence

The model starts with an average figure for visitor days at the reservoir This number is adjusted according to the water level If the level is high for that particular month, an additional percentage of visitors is added to the expected visit rate. This number is then multiplied by a dollar value of between $0 50 and $1 50 that varies according to the month and the water level The total figure is the dollar value of the recreation for that time period and at those water levels The incremental benefit of better information is found by hypothesizing conditions with better information and comparing it to conditions without that information

c Results in the Pacific Northwest

The results of applying the recreation evaluation model to the Grand Coulee Dam and F D R Lake area are presented in Exhibit II-41 Each figure in the matrix represents the dollar value of the recreation for a particular month at a particular water level The expected value of $1,219,600 represents current figures without satellite information These numbers are underscored The matrix numbers that are in parentheses represent the hypothesized values at new water levels resulting from better information The total value of this recreation is $1,306 100, hence, the incremental benefit of information is $86,500

EXHIBIT II-41 VALUE OF RECREATION AT GRAND COULEE DAM AND F.D.R LAKE (Figures in Thousands of Dollars)

	Water Level (Reference 1200 Ft)																		Expected Recreation Values	Recreation Values with Satellite Info
	90 0	89 5	89 0	88 5	88 0	87 5	87 0	86 5	86 0	80 0	70 0	60 0	50 0	40 0	30 0	20 0	10 0	00 0		
January	15 3	13 9	13 2	12 1	11 3	11 1	10 2	9 8	9 4	7 9	(7 9)	7 9	7 4	7 4	7 4	7 4	7 4		9 4	7 9
February	18 6	15 7	15 2	14 8	14 1	13 3	12 9	12 5	11 6	9 5	9 1	9 0	(8 1)	8 1	8 1	8 1	8 1		9 5	8 1
March	42 4	36 3	34 7	33 0	31 0	28 8	28 7	27 4	24 0	20 4	19 2	18 7	16 2	(16 2)	16 2	16 2	16 2		19 2	16 2
April	53 2	46 2	45 1	43 2	40 7	37 2	35 6	33 9	30 4	25 0	23 2	22 6	18 9	18 9	18 8	(18 9)	18 9		18 9	18 9
May	99 1	88 5	84 2	80 8	75 7	68 9	65 6	62 3	55 5	45 9	42 4	(41 1)	33 8	33 8	33 8	33 8	33 8		42 4	41 1
June	210 5	(185 2)	166 2	151 1	131 5	115 8	99 1	83 9	60 1	35 4	34 0	34 0	27 0	27 0	27 0	27 0	27 0		151 1	185 2
July	(421 0)	370 5	332 3	302 1	262 9	231 5	197 9	167 7	120 1	70 9	68 1	68 1	54 1	54 1	54 1	54 1	54 1		370 5	421 0
August	(379 1)	333 3	299 5	272 9	238 3	210 5	180 6	153 9	111 8	67 1	64 7	64 7	52 4	52 4	52 4	52 4	52 4		399 1	379 1
September	(159 1)	142 2	135 5	130 1	122 3	111 9	106 7	101 6	91 0	85 2	69 7	67 7	56 4	56 4	56 4	56 4	56 4		142 2	159 1
October	51 8	45 9	43 8	(42 1)	39 6	36 3	34 7	33 1	29 7	24 5	22 8	22 1	18 5	18 5	18 5	18 5	18 5		43 8	42 1
November	29 5	26 1	24 8	24 9	22 5	(20 7)	19 7	18 8	17 0	14 0	13 0	12 7	12 7	10 7	10 7	10 7	10 7		24 9	20 7
December	12 0	9 4	9 2	9 1	9 0	8 8	8 7	8 6	8 5	6 8	(6 7)	6 7	6 5	6 5	6 5	6 5	6 5		8 6	6.7
																			$1 219 600	$1 306 100

Expected Values are underscored

Values with Information are in parentheses

Incremental Benefit $86,500

More benefits might be realized if more recreation areas were constructed on reservoirs Secondary benefits might come from increases in the boating, fishing, and other related businesses Although these are benefits that would have a positive impact upon the area, they could not be estimated within the scope of this study

The benefits found on the F D R Lake can be extrapolated to the entire Pacific Northwest drainage basin by examining the ratio of usable storage volume in the rest of the basin to that of this reservoir It is assumed that the impact of the satellite will be directly proportioned to the amount of water that can be held behind each dam The effect of higher and steadier stream flows will be neglected Thus, in the Pacific Northwest there are roughly 18,500,000 acre-feet of reservoir storage compared to the 5,232,000 acre-feet behind Grand Coulee Dam. Total benefits are increased by this ratio to $305,000

It should be recognized that a number of assumptions and generalizations were made to arrive at this figure Population distributions will, of course, affect the number of visitors that can benefit from better controlled reservoirs The final figure is offered only as a best estimate of what recreation benefits would be

E Satellite Constellation Analysis

The sections above have established the user sensor model, the subbasin forecasting model, the river user decision model, and the calculation of benefits relative to power, flood control, irrigation, and recreation These benefits were dependent upon a particular sensor package and a 6-hour coverage of the Pacific Northwest This section describes the major considerations involved in selecting the number and orbital characteristics of the satellites needed to support the water-management case in the Northwest.

The required satellite constellation must provide the required orbital coverage to selected geographical areas with the lowest number of satellites At the same time, the constellation must also remain sensitive to certain mission requirements Premature selection of these requirements can only reduce the scope of possible constellation configurations

Therefore, in developing a satellite constellation, it has been decided to adopt a parametric approach, rather than postulate exact requirements. Whenever final requirements can be established for a multipurpose system, then an optimum constellation configuration shall be synthesized, using the methodology developed herein

1 Definition of Geographical Areas

The area of interest for the regional water management study is the Columbia River Basin in the Northwest United States, for our purpose, this area need only be defined as lying between longitude 125° and 110° W and between latitude 42° and 52° N (The area to be observed for the wheat rust is the North American continent, from about latitude 20° to 58°N For the Global Grain Inventory Yield, the areas that must be covered extend mostly around the world up to latitude 58° N and down to latitude 50° S)

2 Requirements Analysis

The selection of an acceptable satellite constellation depends largely on satisfying three sets of requirements The first

requirements are those that are sensitive to orbital parameters These requirements are usually derived from the spacecraft sensors and include the orbital altitude, the viewing angle of the sensor, and the swath width subtended by that viewing angle For a given swath width and sensor viewing angle, there is a minimum altitude that meets these requirements, on the other hand, too high an altitude reduces the available signal to the sensor and correspondingly reduces the desired resolution

Secondly, certain requirements are dependent on geographical characteristics For instance, the orbit inclination angle also defines the highest (or lowest) observable latitude If the highest latitude of the area to be mapped is L, then the inclination angle must be at least equal to or greater than L minus one-half swath width

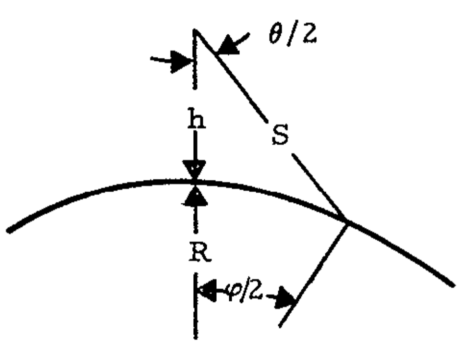
The last set of requirements is a function of the timeliness of the data to be collected, e g., the frequency of coverage of a particular area, the maximum time duration between successive looks, and the availability of a ground station to receive the data as soon as possible

In order to obtain an optimum constellation, satellite coverage analyses are conducted in three separate steps This three-way approach is consistent with the requirements structure previously identified

a <u>Orbit Analyses</u>

The first step is to analyze and obtain the most suitable orbit that meets the sensor requirements The approach taken here has been to describe the relationship between swath width, orbit altitude,[1] sensor viewing angle, and the slant range This relationship can be expressed as follows

$$h = R\left[\frac{\sin(\theta/2 + \varphi/2) - 1}{\sin \theta/2}\right], \text{ (n mi)} \tag{1}$$



[1] Throughout this analysis, the orbits have been assumed circular

where h is the orbital altitude in n mi

R is the mean earth radius = 3,438 n mi

$\theta/2$ is half the sensor viewing angle in degrees

$\varphi/2$ is the earth central angle subtending the swath width and can be written as

$$\varphi \simeq 2\left[\sin^{-1}\left(\frac{R+h}{R}\right)\sin\frac{\theta}{2} - \frac{\theta}{2}\right] \tag{2}$$

$$U = R\varphi, \text{ (n mi.)}$$

where U is the swath width in n.mi.

$$S = R\,\frac{\sin(\varphi/2)}{\sin(\theta/2)}, \text{ n.mi.} \tag{3}$$

where S is the slant range in n.mi., or the distance between the spacecraft sensor and the ground being viewed

By specifying a maximum θ (constrained by sensing capabilities) and a desired swath width, the above expressions can provide the minimum orbital altitude and the corresponding slant range.

Orbital mechanics are now introduced in the analysis to describe the behavior of a satellite in Earth orbit. The Keplerian orbit period is expressed as T for a homogeneous perfect sphere

$$T = 2\pi(R+h)\frac{\sqrt{(R+h)}}{\sqrt{u}}, \text{ (min)} \tag{4}$$

where u is the gravitational constant and $= 2.26 \times 10^8$ n mi $^3/\text{min}^2$ However, since the earth is not a perfect homogeneous sphere, the period of an earth orbit can be more exactly defined as the time interval between two consecutive crossings of the equatorial plane. The crossing point of the orbit at the equator is defined as the node of the orbit, for this reason the true orbit period is defined as the nodal orbit period, or T_n.

As can be seen from Equation (5), T_n is essentially the Keplerian period, T, plus the perturbation effects caused by earth and

anomalies Only first order perturbations are shown in expression (5), note the effects of altitude, h, and orbit plane inclination angle, i, on the true orbit period T_n

$$T_n \approx T \left\{ 1 - \frac{3}{2} J_2 \left(\frac{R}{R + h} \right)^2 \frac{7 \cos^2 i - 1}{4} \right\} \tag{5}$$

where J_2 is the coefficient of gravitational potential function = 1.0823×10^{-3}

Once a satellite is placed in orbit, it can be assumed for our purposes [1] that the orbit plane orientation is fixed in space. The relative motion of the satellite to earth is then mostly attributable to satellite velocity and earth rotation under the orbit plane During one complete revolution, lasting T_n minutes, the earth has rotated λ_t degrees in longitude, where

$$\lambda_t = T_n \, \Omega_e \text{ (degrees)} \tag{6}$$

λ_t is the longitudinal displacement in degrees

Ω_e is the earth rotational rate measured as 360° per sidereal day, 86,164 sec. = 0.2507 degrees/min

Note that λ_t is only a function of T_n, and remains constant for any latitude, except the poles

b Mapping Analyses

The second step is to analyze the orbit coverage and to determine the relationship among various orbital parameters, in order to optimize coverage effectiveness

At this time, two important relationships must be investigated One is the longitudinal displacement between consecutive orbits λ_t, which remains constant when measured in degrees Actually, if λ_t is to be measured in n mi, the longitudinal displacement is maximum at

[1] In actuality, this assumption is not exact because of the precession of the orbit nodes, a $\sin^2$ function of i

the equator, and approaches zero as the latitude increases to the highest point viewed by the particular orbit Swath width subtended by the sensor, on the other hand, remains constant regardless of latitude position, therefore, swath widths that afford little or no overlap at the lower latitudes begin to overlap each other as the latitude increases

The second relationship is based on the fact that a satellite spends more time at higher latitudes, e g , those latitudes equivalent to its orbit inclination angle, than at lower latitudes This relationship can be expressed analytically as follows

$$p = \frac{\sin^{-1}\left(\frac{\sin L_1}{\sin i} - \sin^{-1}\frac{\sin L_2}{\sin i}\right)}{180^{\circ}} \tag{7}$$

where p is the percent of time spent between two latitudes, L_1 and L_2, if $L_1 > L_2$

i is the orbit inclination angle $\geq L_1$

Calculations for the Columbia River Basin where L_1 is 52° and L_2 is 42° yield

$$P = 10.8 \text{ percent for } i = 55^{\circ}$$
$$P = 5\ 5 \text{ percent for } i = 90^{\circ}$$

Thus, a 55° inclined orbit is about twice as effective in providing coverage between latitude, 52° and 42° than a 90° inclined, or polar, orbit

To facilitate the evaluation of orbital parameter relationship on area coverage, a computer program has been developed Given altitude, orbit plane inclination, swath width, and area to be covered as inputs, this computer program generates continuous ground swaths over the specified area for one or more days A graphical plot of these daily tracks gives the percent of area viewed, P, by one satellite, in one day

This percent, p, shall fluctuate daily, however, on a long-term basis, this is equivalent to saying that a point located centrally between the two latitudes of interest, L_1 and L_2, shall be covered P percent of the days

Several computer runs have been plotted and the corresponding results are shown in Exhibit II-42, for a variety of parameters and for all three case studies From these results, the following relationships can be inferred. They are

1 For a given swath width, the orbital altitude[1] of the satellite is almost independent of the percent of area covered

2. Swath width[1] is the most relevant parameter to percent of area coverage The relationship is directly proportional for small swath widths, or where overlap is minimal

3 Increasing the orbit plane inclination angle reduces the percent of area covered between two latitudes, however, it should be recalled that a greater portion of Earth can be observed at higher inclination angles Thus, <u>total</u> area coverage does improve with increased orbit inclination angle

c Constellation Configuration

The last step of the coverage analysis is to determine the necessary constellation that can meet the timeliness requirements, or frequency of coverage Generally, for daily coverage, one satellite is sufficient, however, two or more satellites can be judiciously placed to improve greatly the percent of area viewed daily

For the Northwest water management case, it appears desirable to have four viewing opportunities per day, spaced as equally as possible The orbital constellation should then consist of four satellites appearing at the same point on Earth, 6 hours apart, the result is four orbital planes, with their respective ascending nodes (at the equator) 6 hours apart The same constellation will prove adequate for the coverage required by the wheat inventory/yield and rust cases The probabilities of coverage of the one constellation for the three case studies are shown in Exhibit II-43

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[1] In reality, it should be recognized that swath width and altitude are somewhat related by the maximum sensor viewing angle θ

EXHIBIT II-42 PERCENT OF AREA THAT CAN BE VIEWED DAILY BY ONE SATELLITE VERSUS ORBITAL PARAMETERS, FOR THREE CASE STUDIES

Case Study	Orbit Inclination Angle (°)	Orbit Altitude (n.mi.)	Swath Width (n.mi.)	Area Viewed by a Single Satellite Per Day (percent)
Hydrology (Latitude 42° to 52°)	55	150	100	44
	55	150	40	19
	55	150	240	76
	55	350	100	43
	55	485	250	76
	55	500	320	94
	70	150	240	57
Wheat Rust (Latitude 20° to 58°)	55	150	240	66
	55	500	320	73
	70	150	240	63
Inventory Yield (Latitude 0° to 58°)	55	150	240	58
	55	500	320	66
	70	150	240	55

EXHIBIT II-43 PROBABILITIES OF COVERAGE FOR THREE CASE STUDIES (55° ORBIT INCLINATION ANGLE, 360-N MI SWATH WIDTH,(1) 500-N.MI ALTITUDE)

Case Study	Desired Frequency of Coverage (Daily)	Latitude Band To Be Observed (Degrees)	Probability of Coverage			Number of Equally Spaced Orbit Planes
			With 1 Satellite	With 2 Satellites	With 4 Satellites	
N W Water Management	4	42 to 52	Not Applicable	Not Applicable	93 8	4
Wheat Rust	2	20 to 58	Not Applicable	72 6	92 5	2 or 4
Global Grain Inventory Yield	1	0 to 58	66 0	88 3	98 6	1, 2 or 4

Note (1) Small variations in the swath width will not seriously affect the probability of coverage

F Information System Configuration

Having described the sensor package and the satellite constellation required for the Northwest water management case, it is appropriate to describe the information system configuration Given the sensor output it must be communicated to the ground into an analysis and interpretation center and subsequently disseminated to the ultimate user This portion of the overall system can be called the information system This system is described and thus sets the stage for the calculation of system costs found in the section following this one

It should be emphasized that the information system designed for the study is by no means the only technically feasible solution The system as shown is within the state-of-the-art, and the purpose of this section is to illustrate system configuration It is stipulated that the technical features specified are subject to analysis and adjustment during the actual design period

The stipulation was made at the beginning of the study that three levels of technology would be investigated for system design These would parallel the design of the Earth Resources Technology Satellite (ERTS) program (1970-1973) and the design of two advanced-level technology programs within the Earth Resources Satellite (ERS) program (1973-1990) The current, or ERTS, program can be considered largely experimental This program requires three operational spacecraft. The advanced, or ERS, program requirements are far more expensive and complex The requirements of the user decision models can be met with the first advanced level of technology ERS system For the reasons stated above, only one advanced technology system is designed, discussed, and costed in the study The ERS system can be considered to include the ERTS system and costs and performance figures for ERTS can easily be derived if desired Investigation of a second advanced-level technology would not be fruitful because expected sensor development during advanced level 1 will satisfy the requirements of the user decision models

The proposed information system is represented schematically in Exhibit II-44 For the ERS system, it will be seen that one satellite constellation is sufficient for multipurpose applications water management wheat stress, and agriculture inventory/yield A constellation of

four satellites in an inclined orbit of 55°, an altitude of 500 nautical miles (n mi), and a swath width of 330 n mi will provide acceptable area coverage of the Columbia River Basin The Basin, with an area of about 300,000 square miles, will be crossed by the four satellites four times each day North American wheat areas totaling over 330,000 square miles will be covered acceptably twice each day, and worldwide wheat areas, comprising about 2,700,000 square miles, once each day A total of 68 operational spacecraft will be required for the system, assuming a mission lifetime of 16 months and reliability factors of 0 9 each for the spacecraft and launch vehicles An operational system spanning 18 years will permit a production run with a learning curve applicable to spacecraft fabrication

The basic operation in the information system is the acquisition of ground data by a spacecraft sensor package The package includes three sensors a seven-channel multispectral scanner (MSS), a three-channel color TV system, and radar The radar system will be capable of ground mapping and detection of precipitation The seven channels of the MSS will include three channels in the visible light region and four in the near-infrared and thermal infrared regions The sensor package weighs about 700 pounds and requires about 1,000 watts of power

It should be emphasized again that the system measurements specified in the design of the system are parametric in nature and serve primarily to illustrate general system capabilities

The total estimated weight of a single satellite package is about 2,800 pounds To lift the payload to an orbit of 500 n mi and into a circular 55° inclined orbit requires a TITAN IIIX/HOSS booster, assuming development of no new launch vehicles

The ground link channel-to-receiving stations will require an information bandwidth of about 0 5 mHz at a 30-percent duty cycle To supplement existing NASA tracking facilities, five ground receiving stations will be constructed to track the satellites and collect sensor data Data from the ground receiving stations will be communicated to the Interpretation and Analysis Center (IAC) through leased wideband communication circuits It is estimated that the ground network bandwidth required to carry both hydrological and agricultural data from the receiving station to the IAC is about 4 mHz, while worldwide agriculture yield data will require approximately 48 mHz through information transfer satellites

The IAC designed for each of the satellite systems described in this report serves several purposes It is a command and control center to monitor the satellites around the clock, and to produce tapes to be used by the groundstations to interrogate the satellites and to command their sensors Secondly, it is a processing facility for data from the satellites Personnel and equipment are provided in the IAC to receive, reformat, edit, scan, display and interpret the data to reduce it into form useful for decisionmaking Once the data have been reduced to the desired form, the IAC serves as a dissemination point from which predictions will be sent to the requesting users

For the applications under consideration, processing requirements are based on the fact that it will not be necessary to cover 100 percent of the area of concern all of the time Rather, a sampling technique will be used to process data for only those areas known from ground observations and predictions to be of interest

A combined IAC for both hydrology and agriculture is assumed, although details of separate facilities are discussed in the supporting Appendix Costs of a single center are considerably less than the combined cost of the separate facilities since a single center avoids some duplication of personnel and equipment The IAC was designed to have the capability to perform all the known tasks required during a "peak" day and so that photo processing and pattern recognition for both applications could be accomplished simultaneously

Exhibit II-44 illustrates the major steps in the processing of data at the IAC Data in the form of an FM signal containing several channels of sensor and housekeeping data will be transmitted from the satellite to the IAC via a ground receiving station The signal will be recorded on a master tape for "back-up" and will simultaneously be decommutated or separated into discrete signals for each channel of each spacecraft sensor Each signal must also be converted into digital form by a series-to-parallel converter

Video data or data from one or more channels of the multispectral scanner will be converted into analog form and fed directly into a display device that exposes film that will be developed in the photo

FOLDOUT FRAME 1

FOLDOUT FRAME 2

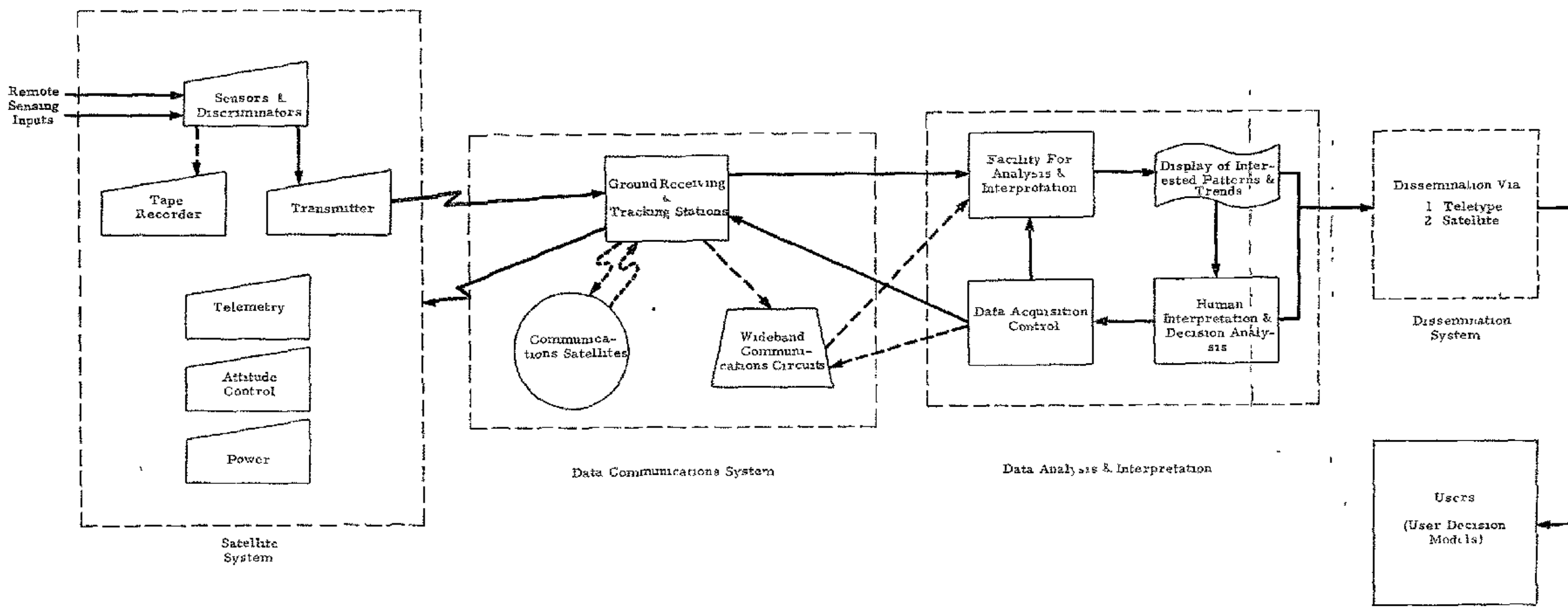

EXHIBIT II-44 GENERAL INFORMATION SYSTEM CONFIGURATION

lab The display device can add predetermined latitude-longitude grids to the photographs, which will be utilized by photo interpreters The video data may also be used to determine the area viewed by the sensors Photographs could be calibrated against a map to determine location to the nearest resolution element of the sensor

It may also be desirable to feed the digital video signal into the digital computer for processing The digital computer can be programmed to "mosaic" and grid several frames, whereas the analog method is limited to producing photographs of single frames

Digital processing of multispectral scanner data will primarily consist of computing temperature and surface moisture percentage by resolution element Automatic corrections for atmospheric and surface conditions and differing instrument calibrations may also be possible Outputs will be one or more of the following types Alphanumeric listings that display parameters by resolution element or summation of parameters by specified geographic areas, digital tapes containing information to be fed into the x-y plotter, digital tapes to be used by automated analysis models, and magnetic tapes to be used in photo processing

Multispectral scanner data will also be processed by the analog computer to detect the existence of wheat, determine its stage of growth, and determine if wheat rust is present The computer can also accumulate these parameters by specified areas The results can be used to estimate wheat yield and assist in controlling the spread of wheat rust This type of processing, called "pattern recognition," can be accomplished approximately 1000 times faster by an analog computer than a digital computer State-of-the-art for this particular requirement for pattern recognition, however, is such that a long R&D program might be necessary before processing can become fully operational An alternative or supplemental method would be to produce either black and white or color photographs with signals from one or more of the scanner's infrared channels The disadvantage of this method, of course, is that it requires a substantial manual effort for photo interpretation

Radar data will be received and coherently detected in the satellite The resulting video will be used to directly modulate the satellite-to-earth data link This method, as opposed to onboard recording, provides the minimum delay in obtaining the data In the water management case in particular, this is a significant advantage The recorded signal film will be processed with existing coherent optical processors to produce the final output maps

The IAC has been specifically designed to produce the following principal outputs for the water management application

Principal Outputs

- Isothermal maps and/or temperature listings
- Snow area in square miles or in map form by specified geographic areas
- Indications of snow depth
- Soil moisture and areas of recent precipitation
- Aerial distribution and intensity of precipitation
- Stream widths and areas of marshes, lakes, etc
- Cloud cover

For the agricultural inventory and yield case, the IAC will produce the following outputs

Inventory/Yield Outputs

- Acreage of plowed and harrowed land by specified geographic area
- Identification of wheat fields and stages of growth
- Cloud cover
- Ambient temperature
- Snow area, when applicable
- Plant reflectance
- Surface moisture
- Aerial distribution and intensity of precipitation
- Measures of stress

The facility will also meet the following output requirements for use in detecting and forecasting wheat rust

Rust Outputs

- Crop identification and stages of growth
- Area and intensity of rust
- Ambient temperature
- Soil moisture
- Existence of free moisture (dew)
- Wind direction and velocity

The analysis and interpretation function includes more than the analysis of the basic sensor data The sensor data will be sample data and often only inferentially related to the estimates that must be made for ultimate decisionmaking Snow area and indications of depth must be converted into snow volumes and water equivalent estimates Days of sunshine, rain, soil moisture, etc must be used to estimate wheat yield Signs of rust, wind patterns and weather conditions must be used to project potential rust infection many miles away from the original sightings of rust Thus the sensor data must be incorporated into various relationships that must be fully established for incorporation into the user sensor models

Given estimates of water equivalents, flow rates, wheat inventory and yields, and potentialities for the spread of rust, additional factors must be taken into account before recommending action to decisionmakers Before action recommendations are made, for example, in the wheat production case, a number of other important factors must be integrated into a decision model Before a recommendation for increasing wheat output suggested in the face of a short wheat crop, it is necessary to consider the time of year, the area that can increase production, the estimated size of competitive crops, producer options, consumer preferences, international agreements, balance of payments, etc Thus, both economic and political elements must be worked into the decision model and the judgment of decisionmakers included as a significant feedback loop in the process, allowing comparisons with past experience in formulating projections of wheat production and the effects of suggested remedial actions The use for complex decision models can be envisaged from the present study, they could not be formulated within the scope of the funded effort

Existing domestic communications channels are adequate for disseminating information generated by the IAC Domestic leased lines are capable of relaying hydrologic data to the central control group within the specified 6-hour limit Established communications facilities between current operations centers and dams are sufficient to maintain control The existing control system in the Northwest is partially automated, and even where it is manual, it is capable of continuous contact

Expansion of the information system into other parts of the United States will require additional central control facilities, however, given that automation of dam management will increase, the domestic communication system appears fully capable of handling the control link through the foreseeable future

Operational response time for the wheat yield inventory case is not as immediate The 1-week time frame allows any number of alternatives for transmission of data USDA Economic Reporting Service remains the logical injection point for wheat inventory yield projections Although yearly yields directly affect the world commodity situation, economic and political considerations also influence the market flow The existing Department of Agriculture information system provides a good means of dissemination Diplomatic channels will carry wheat projections of an individual country through the regional Foreign Agricultural Service attachés Global wheat projections will be released to the United Nations' Food and Agriculture Organization and the International Wheat Council through representatives in Washington, D C Since satellite-derived wheat data will primarily augment information currently compiled, dissemination procedures to State Extension Service, news media, and agri-business concerns will remain unchanged

A wheat rust information system will require the implementation of a communication link between the IAC and State Extension Services in wheat growing areas The nature of the disease requires a rapid direct link with the local operator for most effective results Once the information is carried to the Extension Service, existing dissemination systems adequately provide channels to ultimate users The Services

maintain close cooperation with land grant universities, farm cooperatives, and county agents The State Extension Services provide twice daily radio and television farm news programs of local production and marketing interest The Services provide an automatic answering device in the telephone system for communicating news briefs to the farmer Both this device and the daily farm news broadcasts provide excellent channels for dissemination of wheat stress

G System Costs

The sections above have described all of the major components of the operational system Benefits have been calculated for the water management case and their comparison with system costs is the next logical step Actually the costs of the operational system proposed for the water management system can be used as the basis for a multipurpose system comparison including the water management, wheat inventory/ yield, and wheat rust cases Incremental costs, for example, like spraying in the wheat rust case, are subtracted from the benefit side for ease in presenting that case

Detailed cost information is contained in Appendix D. The following is a brief information system cost summary and sensitivity analysis.

1 Satellite Program 1970-1990 System

System costs for the total program are presented in Exhibit II-45, broken down into costs for launch vehicles, spacecraft, data analysis, and interpretation and communications for the system with the radar, TV, and MSS The total undiscounted cost is $2,504 5 million or $1, 502 7 million at 7 5-percent discount rate, $1, 338 4 million at 10-percent discount rate, and $1, 187 1 million at 12 5-percent discount rate

2 Spacecraft System Satellite Program R&D

From the requirements and specifications above a spacecraft system evolved that encompassed a current level of technology system with three spacecraft, patterned after an accelerated ERTS program and an advanced level system with 67 flight spacecraft Spacecraft system costs were built up from the subsystem level and include design and development, first unit cost of test and flight spacecraft, aerospace ground equipment, tooling and special test equipment, systems integration and such mission support operations as procurement phases, advance development, systems engineering and technical direction, and program management Estimates of systems costs are based on technical factors

EXHIBIT II-45 SATELLITE PROGRAM 1970-1990 SYSTEM COSTS (IN MILLIONS OF DOLLARS)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
R&D																						
Earth Sciences	25 0	25 0	20 0	4 0	4 0																	78 0
Sensor Equipment	39 0	50 0	50 0	16 0																		155 0
Sensor Data Acquisition	10 0	10 0	15 0	15 0	10 0																	60 0
Sensor Data Processing & Rectification		5 0	6 0	10 0	5 0																	26 0
Automatic Data Interpretation			10 0	20 0	17 0	15 0	10 0															72 0
Historical Data Bank	2 0	2 0	1 5																			5 5
Decision Analysis		3 0	4 0	3 0	3 0																	13 0
Investment & Operations (With Radar & TV)																						
Launch Vehicles	0 0	7 1	14 2	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	532 5
Spacecraft	46 3	160 7	120 1	73 8	73 8	72 8	69 7	65 6	63 3	62 4	61 3	60 8	59 9	59 2	58 8	58 8	58 3	58 1	57 9	57 4	57 4	1 456 4
Analysis & Interpretation	0 0	2 6	2 4	2 5	2 6	2 6	2 5	2 5	2 4	2 4	2 4	2 3	2 3	2 3	2 2	2 2	2 1	2 1	2 1	2 1	2 1	46 7
Communications	2 0	3 9	3 8	3 6	3 5	3 3	3 2	3 1	3 0	2 8	4 7	2 6	2 6	2 4	2 4	2,3	2 2	2 1	2 0	2 0	1 9	59 4
Total (0 Percent Discount Rate)	124 3	269 3	247 0	176 3	147 3	122 1	113 8	99 6	97 1	96 0	96 8	94 1	93 2	92 3	91 8	91 7	91 0	90 7	90 4	89 9	89 8	2 504 5
(7-1/2 " " ")																						1 502 7
(10 " " ")																						1 338 4
(12-1/2 " " ")																						1 187 1
Investment & Operations (MSS Only)																						
Launch Vehicles	0 0	3 2	6 3	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	223 7
Spacecraft	25 9	89 9	67 2	41 3	41 3	40 7	39 0	36.7	35 4	34 9	34 3	34 0	33 5	33 1	32 9	32 9	32 6	32 5	32 4	32 1	32 1	814 7
Analysis & Interpretation	0 0	2 6	2 4	2 5	2 6	2 6	2 5	2 5	2 4	2 4	2 4	2 3	2 3	2 3	2 2	2 2	2 1	2 1	2 1	2 1	2 1	46 7
Communications	2 0	3 9	3 8	3 6	3 5	3 3	3 2	3 1	3 0	2 8	4 7	2 6	2 6	2 4	2 4	2 3	2 2	2 1	2 0	2 0	1 9	59 4
Total (0 Percent Discount Rate)	103 9	194 6	186 2	127 3	98 3	73 5	66 6	54 2	52 7	52 0	53 3	50 8	50 3	49 7	49 4	49 3	48 8	48 6	48 4	48 1	48 0	1 554 0
(7-1/2 " " ")																						1 010 0
(10 " " ")																						892 7
(12-1/2 " " ")																						798 8

such as weight, thrust, and kilowatts of power as well as cost factors such as the spacecraft total procurement cost A breakdown by cost element and year for the spacecraft program is shown in Exhibit II-45

Since the ERTS level system is based on existing technology and may involve existing spacecraft types and some off-the-shelf subsystems components, a modest design and development effort was assumed The ERTS system is essentially a large test program running concurrently with studies and development for the advanced level system which becomes operational in 1973 A continuous production run is assumed for the advanced system with a learning curve of 95 percent applied beyond the first 10 units since the user decision models are based on requirements that can be met by the specifications of a single advanced level spacecraft system Although the possibility of engineering change orders, systems improvements, and continued development is recognized, their incidence is neither required nor inevitable, and they were not explicitly added to the cost estimate

In Exhibit II-45 the R&D costs associated with ERTS are to be found under Investment Costs In addition to these costs, considerable developmental R&D is required in a number of areas Sensor R&D is required to develop the state-of-the-art identification, resolution, etc , projected for the operational system at altitude This will cost approximately $155 million The next most expensive element involves R&D in the earth sciences Techniques must be established and standardized for projecting snow water equivalents from area, volume, and other measurement It is necessary to devise and test estimating techniques for predicting runoff from snow pack with various temperature patterns It is necessary to calibrate marshes, lakes, and flood plains as indicators of stream flow These and similar tasks will probably cost about $78 million The problem of obtaining an automatic data interpretation system will only be slightly less costly This will entail expenditures of about $72 million and will be aimed at gradually phasing out human interpreters for automated processes The data transmittal problem or acquisition problem is fairly significant, and although sampling techniques should reduce its total magnitude, it can be expected that something like

$60 million dollars will need to be expended in this area Sensor data processing techniques and rectification associated with base data prior to interpretation might cost about $26 million The decision analysis models and associated software should cost about $12 million and the supporting historical data bank, something like $5 5 million These and other costs are defined in greater detail in Appendix D

3 Launch Vehicle

Selection of a suitable launch vehicle is an iterative process as is the choice of a spacecraft, the other major cost component

To place the 2800-pound spacecraft in a circular, 55° inclined orbit at 500 n miles altitude, the launch vehicle selected was a TITAN III X/HOSS The payload will be injected first into a 100-n mile orbit with a combination dog-leg and Hohmann transfer into the required orbit The cost per launch is $3 155 million, which includes manufacture (assembly), factory checkout, shipping to launch site, erection and checkout at launch site, launch costs, and costs for sustaining launch crews

4 Interpretation and Analysis Center

In addition to the system specifications previously outlined, costs are based on the following assumptions The amount of internal processing time for the digital computer is determined by the assumption of 100 additions per character Total data processing time is assumed to be 1 hour every 6 hours for the hydrology case and 10 hours per day for the agriculture cases No more than 20 percent of the total area of coverage will be processed during the total data processing time for each case The system costs are composed of the initial investment in equipment and the recurring costs of personnel, analysis and programming, computer rental, and rental of facilities

5 Communications

Ground receiving stations track the satellite and collect data from the satellite sensors, a data communication network transmits the data to the analysis and interpretation facility It is assumed that

spacecraft tracking will be performed by the Office of Tracking and Data Acquisition. Additional tracking will be necessary, however, to locate the satellites precisely for accurate analysis and interpretation. To collect data for the hydrology and two agriculture cases, five ground receiving stations will be constructed, one each in the Northwest, North Central, and Middle Atlantic sections of the United States, and in northeast South America and Ascension Island. The latter three are to be located contiguous to Comsat-Intelsat earth terminals.

Based on a 10-year lifetime, the investment cost of $394,000 for each ground receiving station includes a 42-foot x-y tracking antenna, electric components made up of receivers, amplifiers, tape recorders, transmitters, and computer equipment associated with command and encoding functions, an allowance for maintenance float, and initial spares as well as the building itself. The annual operating and maintenance costs of $118,400 per station are based on the assumption that one supervisor and eight technicians are operating the station 24 hours per day.

As the data are received from the satellite at the ground receiving station, they must be communicated to the central analysis facility. This will be accomplished through the leasing of wideband communications circuits from common carriers such as AT&T. Both ground networks and communication satellites will be used. It was assumed that approximately 3,000 miles of wideband (4 mHz) circuit will be required within the United States to accommodate the three domestic ground receiving stations at a cost of $30 per mile per month for an annual cost of $1.08 million. This assumes a communications response factor of six, which would communicate any 10-minute readout within an hour.

Only agricultural yield data will be collected at the two ground receiving stations outside the continental United States. Both these will be connected to the analysis and interpretation facility by the Comsat-Intelsat circuits at an annual cost of $2.26 million. With the widespread use of communications satellites, cost reductions are anticipated and these circuit rental charges reduce at 5 percent a year. Only for this application will an on-board tape recorder be required. A tape recorder,

currently in the final stages of development by several manufacturers, will be capable of recording up to 30 minutes of 4 mHz data and will cost approximately $0 3 million per unit

6 Sensitivity Analysis

Sensitivity analysis can be a powerful tool in making tradeoff analyses between program requirements and the resultant systems specifications Tradeoffs can and must be made between frequency of observation and number of spacecraft required, weight of the spacecraft and launch vehicle costs, sensor resolution and the cost of analysis and interpretation Some tradeoffs, those involving numbers of spacecraft for instance, are more important than others since the spacecraft system costs represent nearly 60 percent of the total program cost The following sensitivity calculations were based on a satellite with a 1,000-pound payload The scopes of the various figures would not be significantly changed for the 2,800-pound payload proposed

Sensitivity of total spacecraft systems cost to sensor swath width and frequency of observation is illustrated in Exhibit II-46 for an example satellite constellation designed to give a probability of unity in coverage of the Columbia River Basin (with some redundant coverage) at the specified frequency of observation The sensitivity of total program costs would roughly parallel those shown for the spacecraft For the small area of coverage, costs are more sensitive to swath width than to frequency of observation, since a minimum number of spacecraft are required beyond a certain swath width for a given frequency of observation For a larger area of coverage, however, costs would be almost equally sensitive to either parameter since the number of spacecraft required varies with swath width and frequency of observations

The number of satellites required at a time is indicated in parentheses at the appropriate coordinates, which allows estimation of the sensitivity of total spacecraft costs with changes in satellite requirements whether these changes be introduced from desired changes in swath width, frequency of observation, orbit characteristics, or probabilities of area coverage Exhibit II-47 illustrates the sensitivity of total

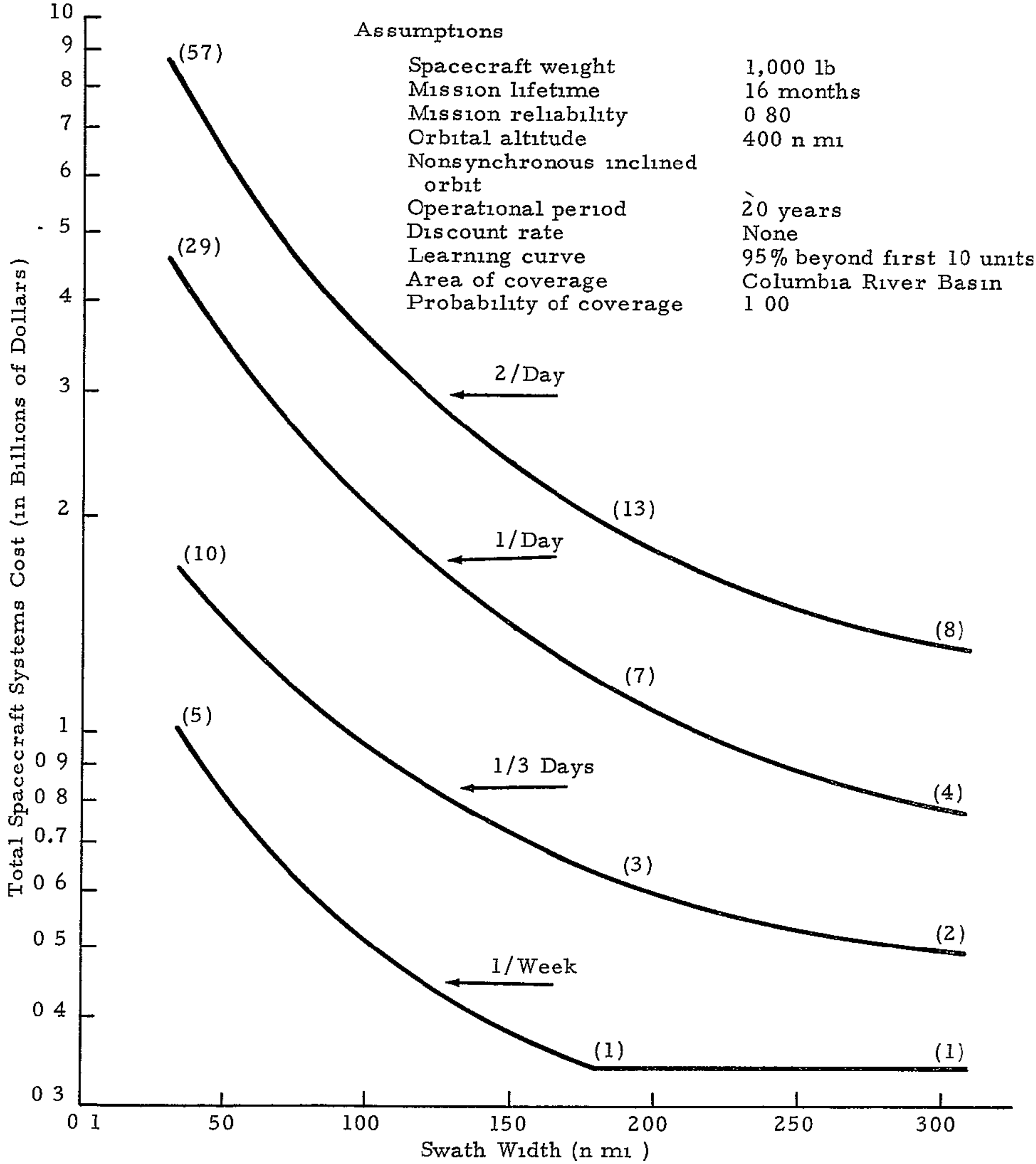

EXHIBIT II-46 SENSITIVITY OF TOTAL SPACECRAFT SYSTEM COST TO SWATH WIDTH AND FREQUENCY OF OBSERVATION

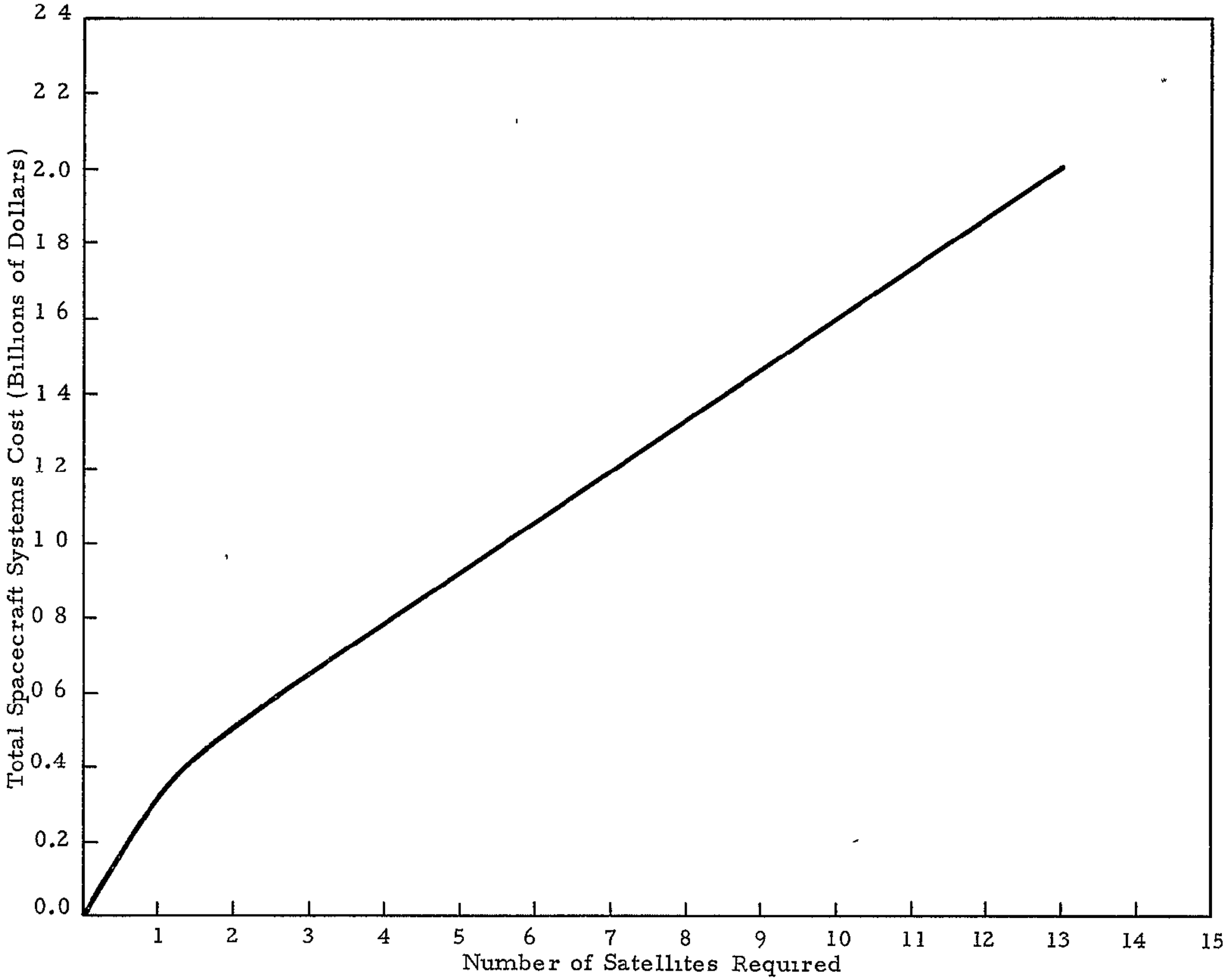

EXHIBIT II-47 SENSITIVITY OF TOTAL SPACECRAFT SYSTEM COST TO NUMBER OF SATELLITES REQUIRED

spacecraft costs with the number of satellites required, given the spacecraft costing assumption used in this example of 1,000-pound payload, 16-month mission lifetime, and 0 8 mission reliability [1] Due to fixed costs in facilities and research and development, a doubling of the required number of satellites, for example, would result in a new system cost less than double the old cost

The more critical spacecraft cost assumptions include mission lifetimes, payload weight, and mission reliability The sensitivity of spacecraft unit costs with payload weight and mission lifetimes are to be found in exhibits provided in Appendix D

The sensitivity of analysis and interpretation costs, represented here by annual computer rental cost, to sensor ground resolution and processing time is illustrated in Exhibit II-48 The dotted lines on the exhibit show the annual computer rental cost, $400,000, for the base case assumptions of 1,200-foot resolutions and 1-hour processing time If sensor-resolution were reduced to 600 feet, for example, and processing time held to 1 hour, computer rental would increase to approximately $625,000 If the time allocated for processing were increased to 2 hours, however, the computer rental would be about $500,000

Discount rate has a strong influence on total program costs, as shown in Exhibit II-45 For discount rates of 7 5 percent, 10 percent, and 12 5 percent, total program costs are 60 0 percent, 53 5 percent, and 47 6 percent, respectively, of the undiscounted cost Discounting takes on importance if the stream of annualized benefits differs markedly in magnitude over time from the stream of costs Of particular interest to the decisionmaker is the discount rate, if any, at which costs and benefits cross over

Sensitivity analysis can also be a powerful tool in determining the cost effectiveness of potential research and development projects.

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[1] Based on a 0 8 reliability factor for the spacecraft and a 0 9 reliability factor for the launching system

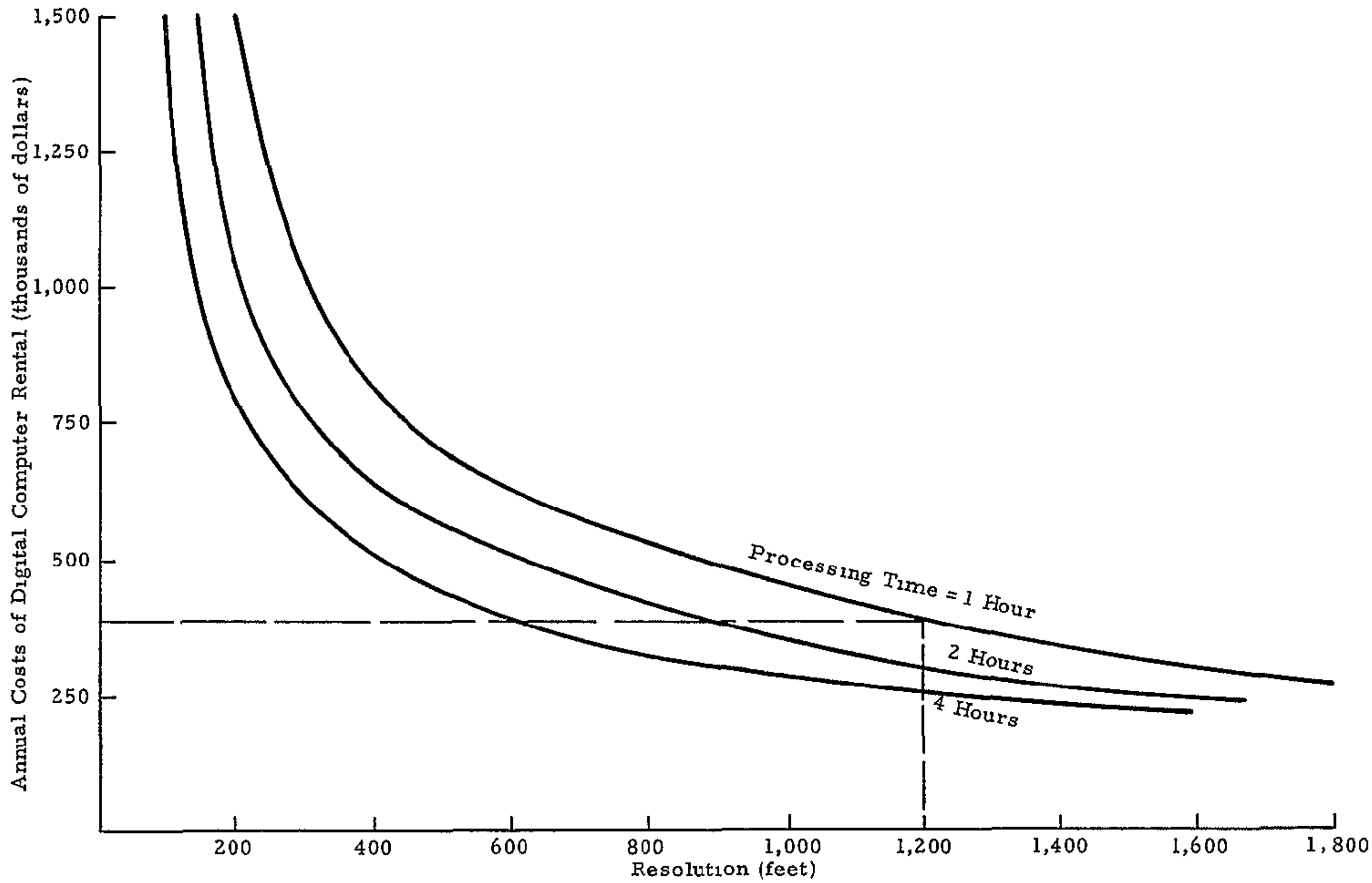

EXHIBIT II-48 DIGITAL COMPUTER COSTS FOR HYDROLOGY IAC VS SENSOR RESOLUTION AND PROCESSING TIME

For example, consider the sensitivity of spacecraft costs to mission lifetime By increasing the mission lifetime, fewer spacecraft would be required, thereby reducing the total program cost The savings in program cost can be considered a threshold If it can reasonably be shown that the desired increase in mission lifetime can be gained by an R&D expenditure of less than the threshold, the project should be considered cost effective

H Summary of Water Management Costs and Benefits in the Pacific Northwest, 1970-1989

Benefits from power, irrigation, flood control, recreation and navigation derived from the satellite system for the Pacific Northwest total 3 4 billion dollars (undiscounted) for the 20-year period, 1971-1990 Power and irrigation account for 93 percent of this total Benefits derived from power exceed those from all other components as shown in Exhibit II-49 The charts in Exhibit II-50 show the rate of increase, for each of the separate components, of the dollar benefits over this same time period

Exhibit II-51 shows the 20-year benefits discounted at 7 5, 10 0 and 12 5 percent for each of the components, for the Pacific Northwest The various costs of the satellite system discounted at these same rates over the same time period are shown on Exhibit II-52

A summary is shown in Exhibit II-53 for the costs and benefits of the various components of water management in the Pacific Northwest, 1971-1990 This exhibit shows that for each of the discount rates used the benefits exceed the costs by some margin if the benefits derived in the Pacific Northwest must cover the total costs of the satellite-assisted system

EXHIBIT II-49 WATER MANAGEMENT DOLLAR BENEFITS (UNDISCOUNTED) FOR THE PACIFIC NORTHWEST, 1973-1990 (Millions of Dollars)

Year	Total Benefits ($)	Power ($)	Irrigation ($)	Flood Control ($)	Recreation and Navigation ($)
1973	86	22 5	44 8	18 5	305
1974	116	50	47	19 0	.340
1975	149	80	49	19 3	375
1976	161	90	51	19 6	400
1977	173	100	53	19 7	425
1978	175	100	55	19 8	450
1979	178	100	57	20.0	.475
1980	180	100	58	21 3	500
1981	182	100	60	21 5	500
1982	184	100	62	22	520
1983	187	100	64	22	550
1984	189	100	66	22	.580
1985	191	100	68	22	600
1986	193	100	70	22	.600
1987	195	100	72	22	675
1988	197	100	74	22	.825
1989	199	100	76	22	900
1990	201	100	78	22	1 000
Total	3,140	1,640	1,110	380	10.0

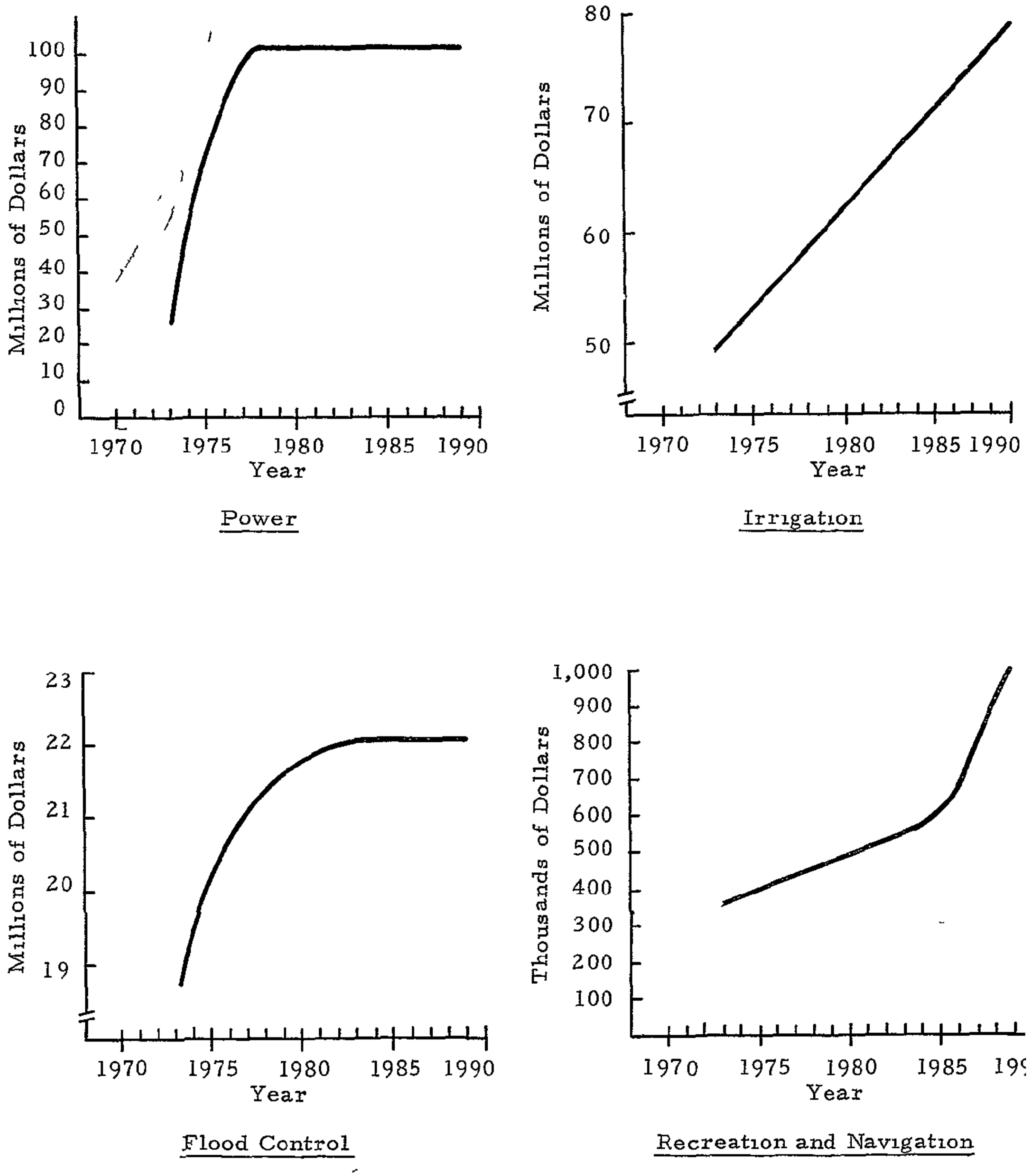

EXHIBIT II-50 WATER MANAGEMENT DOLLAR BENEFITS, BY COMPONENT FOR THE PACIFIC NORTHWEST, 1973-1990

EXHIBIT II-51 WATER MANAGEMENT DOLLAR BENEFITS FOR THE PACIFIC NORTHWEST, DISCOUNTED AT VARIOUS RATES, 1971-1990 (Millions of Dollars) *

	Rate of Discount		
Components	7 5 Percent	10 0 Percent	12 5 Percent
Total	1,809 2	1,512 6	1,285 0
Power	929 4	766 9	644 8
Irrigation	758 3	638 5	548 2
Flood Control	116 2	102 8	88 4
Recreation and Navigation	5 3	4 4	3 6
Total	1,809 2	1,512 6	1,285 0

* While only partial benefits will be realized from ERTS relative to the Advanced I system, benefits have been protected for the entire period at the Advanced I level

EXHIBIT II-52 WATER MANAGEMENT 20-YEAR COSTS* FOR THE SATELLITE SYSTEM DISCOUNTED AT VARIOUS RATES 1971-1990 (Millions of Dollars)

	Rate of Discount		
	7 5 Percent	10 0 Percent	12 5 Percent
Total Cost	1,502 7	1,338 4	1,187 1

* Partial R&D costs are included

EXHIBIT II-53 WATER MANAGEMENT COST BENEFIT RATIOS FOR THE PACIFIC NORTHWEST AT VARIOUS DISCOUNT RATES, 1971-1990

	7 5 Percent	10 0 Percent	12 5 Percent
Benefit/Cost Ratio	1 204	1 134	1 083

I Extrapolation of Water Management Benefits From the Pacific Northwest to the United States

It is possible to estimate the hydrology benefits in other areas of the country by identifying the important variables that reflect the changes in conditions from the Northwest to the other regions The benefits for any one region depend upon geographic and hydrologic conditions, water uses, and management improvements An estimating technique has been developed that is based on the important variables that this study has identified

The benefits that this extrapolation technique has generated are meant only to be a rough estimate of the actual benefits A detailed basin-by-basin systems analysis study would be needed to provide a more accurate picture This type of analysis has not been attempted, and the generalization model is offered only as a substitute

This analysis has divided the continental U S into 14 drainage basins These major drainages are defined by natural drainage features and conform generally to the boundaries adopted by the U S Geological Survey and by the Federal Power Commission Exhibit II-53 identifies these drainage areas

1 The Extrapolation Model

The model will treat each of the major water uses separately Estimates of basin benefits will be based on the magnitude of the current usage, for example, the power benefits on the Mississippi will be calculated as a percentage improvement of the hydroelectric power being generated there now The methodology to be used for each use will be discussed in turn

a Hydroelectric Power Benefits

The studies made of hydroelectric power in the Pacific Northwest showed that benefits resulted in three areas of the water management The first area was in the rule curve drawdown and refill Managers could lower or raise the reservoir water levels more effectively if they were given knowledge of future conditions The study showed these benefits in the Pacific Northwest to be 7 percent of

hydroelectric power sales The second improvement was in a reduction of hedges Dam managers utilize a layer of water as a hedge against variations in water inflows A reduction of this hedge factor because of additional weather and snow data will lead to a 2 percent increase in power sales on the Columbia River The last improvement was in inter-dam coordination By having a better knowledge of flows coming into the mainstream and by being able to coordinate dam releases, the Pacific Northwest could gain 2 5 percent of the hydroelectric power sales

For other watershed regions of the country, these percentages will be different because of the different conditions Variations in dam placement, rain patterns, and geography will affect the percentage improvement that might be expected For each of the three improvement areas, a variable has been selected that seemed directly proportional to that improvement By determining the ratio of that variable in each of the 14 regions to the value of the variable in the Pacific Northwest, a weighting factor can be determined to adjust the Northwest percentage improvements

For rule curve improvements, the variable selected was the percentage of kilowatt hours produced at reservoir generators to the total kilowatts generated Only reservoirs of 0 5 million acre-feet or above were considered This figure will vary as the number of reservoirs increases relative to the run-of-the-river generators Hedge reductions will depend on the variability of inflows and the satellite's ability to predict these conditions The weighting factor for the hedge reductions will be based on the monthly precipitation pattern within each area A variable is determined by first finding the average monthly precipitation The numerator of the variable is the difference of the highest rainfall figure and the average, minus the difference of the lowest rainfall figure and the average The denominator is twice the average Finally, for the interdam coordination improvements, the variable used was the percentage of kilowatt hours produced at run-of-the-river dams to the total kilowatts produced

The equation for power benefits can be summarized by

$$\begin{bmatrix}\text{Hydroelectric}\\ \text{Power Benefits}\end{bmatrix} \text{Region X} = (\text{Hydro Sales})_X \left[W_1(6\%) + W_2(2\%) + W_X(2.5\%)\right]$$

where $$W_1 = \frac{(\text{\% kilowatt hrs at reservoir dams})_X}{(\text{\% kilowatt hrs at reservoir dams})_{\text{Columbia}}}$$

$$W_2 = \frac{\left(\dfrac{(\text{highest monthly rainfall avg}) - (\text{lowest monthly rainfall avg})}{2\ (\text{avg rainfall})}\right)_X}{\left(\dfrac{(\text{highest monthly rainfall avg}) - (\text{lowest monthly rainfall avg})}{2\ (\text{avg rainfall})}\right)_{\text{Columbia}}}$$

$$W_3 = \frac{(\text{\% kilowatt hrs at run-of-river dams})_X}{(\text{\% kilowatt hrs at run-of-river dams})_{\text{Columbia}}}$$

The estimating equation relies on the percentages determined by the analysis made within the Pacific Northwest As more areas are analyzed, that information could be incorporated into both the percentage improvement and the normalizing denominator of the weighting factor A more accurate estimating equation would result as more areas are studied

b Irrigation Benefits

The value of information obtained by the satellite that helps to identify soil moisture content, precipitation forecasts, and runoff forecasts will help farmers by reducing the uncertainty of the water supply for their crops Benefits can be derived in planting, production methods, and harvesting, realizing in advance how the coming year will vary from a normal water supply year Reduced irrigated acreage and the planting of lower water consumptive crops will take place when a year is forecast to be below normal Additional acreage and more intensive crops can be planted in years that are forecast to have above normal water years

Improvements to farming from better weather and water information have been estimated by a Boise, Idaho, economist The irrigation subsection in Appendix C refers to a recent study that relates a dollar value to a range of forecast error reductions It seems conservative to assume that the satellites will make a 15-percent improvement in forecasts Thus, with a 15-percent improvement in forecast ability, an average gain of $9 03 per acre would result To determine the dollar benefits, this figure is multiplied by the number of acres times a precipitation variable factor for each of the 14 drainage subbasins It should be noted that the dollar benefits are based on irrigated acreage for 1959 Therefore, the additional benefits to be derived with increased irrigated acreage through 1990 will be considerably more

c Flood Control Benefits

Flood control benefits within the Columbia River Basin were estimated by examining two specific locations It was calculated that a reduction of 2 feet in peak river stages would translate into a 75-percent saving of flood losses The indirect savings, such as losses in business due to flooding, would be even greater than these direct savings To be conservative, only this 75-percent direct savings was used for generalization purposes The benefits were calculated simply by multiplying 0 75 times direct flood losses

d Recreation-Navigation Benefits

Benefits to recreation and navigation due to better satellite information are derived from higher and steadier reservoirs and streamflows As this report has discussed, the recreation benefits are calculated from the additional visitor days and improved quality of the recreation Within the Pacific Northwest, these benefits have been estimated at $305,000

To extrapolate these benefits to other areas of the country, two variables were used First, the ability of the satellites to affect reservoir recreation will be directly related to the amount of usable storage The ratio of storage in other drainage areas to that of the Columbia

River Basin serves as a weighting factor The second variable that will affect the amount of recreation is the population in that drainage area If there are many more people living near a reservoir, there will be more recreation usage Thus, the population ratio in that area to the Columbia River Basin will be used as a second weighting factor These relationships are summarized in the following equation·

$$\text{recreation benefits} = \frac{\text{(region usable storage)}}{\text{(Columbia usable storage)}} \times \frac{\text{(region population)}}{\text{(Columbia population)}} \times (\$305{,}000)$$

The benefits to navigation were determined to be minor in the Pacific Northwest In other regions of the country, satellites could make a major contribution to river navigation efficiency However, for this generalization model, navigation benefits will be considered to be negligible

e Other Benefits

No generalization or extrapolation can take into account all conditions in each major region of the country PRC has found certain benefits unique to specific regions For example, at the delta of the San Joaquin and Sacramento Rivers, there is a constant salinity problem Managers must keep enough water going out into the bay so that salt does not come up the delta to spoil the farm irrigation However, since water at that location is valued at between \$5 and \$20 per acre/foot, the smallest output necessary is desired This salinity problem was not a consideration in the Pacific Northwest and was not incorporated in this model Likewise, industrial and municipal water supplies were found not to be important In some regions of the country, these uses would be considered as extremely important

2 Results of the Model

The matrix presented in Exhibit II-54 summarizes the results of the extrapolation model The total benefits for the Pacific Northwest are estimated at \$95,248,000, and the total national benefits are estimated at \$553,019,000

It should be stressed that this extrapolation model is only a first cut at what the true benefits really will be Only a detailed study of each watershed basin would be able to properly quantify benefit potential

EXHIBIT II-54 EXTRAPOLATION OF WATER MANAGEMENT BENEFITS

	Pacific Northwest	Hudson Bay	Great Lakes	North Atlantic	Eastern Gulf	Western Gulf	Lower Mississippi River	Upper Mississippi River	Ohio River	Missouri River	Great Basin	South Pacific	Colorado River	South Atlantic	U S Total
Power															
Hydro Total ,	$201 000 000	$ 266 030	$91 587 443	$40 897 509	$21 549,791	$ 4 170 788	$15 725 370	$11 255 992	$75 589 150	$ 50 539 780	$ 4 976 500	$ 86 199 640	$45 429 081	$26 970 405	
a) Drawdown %	6 7%	51	0	0	2 0	6 83	10 58	0	2 31	9 6	0	1 80	13 5	5 1	
b) Hedge %	2 0	4 44	2 04	2 84	2 58	5 0	4 04	3 96	1 80	5 64	5 16	7 20	4 72	1 89	
c) Coordinate %	2 5	9 72	9 9	9 80	8 90	5 32	2 12	9 82	8 32	3 42	9 9	8 72	2 00	6 5	
Total % Improve	11 2%	14 67	11 94	12 64	13 48	17 15	16 74	13 78	12 43	18 66	15 06	17 72	20 22	13 49	
Hydro Total Benefits	$ 22 500 000	$ 39 000	$10 935 500	$ 5 169 400	$ 2 904 900	$ 715 300	$ 2 632 400	$ 1 551 100	$ 9 395 700	$ 9 430 700	$ 749 500	$ 15 274 600	$ 9 185 760	$ 3 638 300	$ 91 122 160
Irrigation															
Acres Irrigated 1959	4 966 000	47 000	40 000	178 000	101 000	5 655 000	1 394 000	101 000	64 000	6 298 000	1 603 000	7 395 000	4 568 000	597 000	
Benefits	$ 44 843 000	$ 412 000	$ 223 600	$ 754 720	$ 391 880	$12 355 950	$ 8 433 700	$ 619 840	$ 172 800	$ 53 407 000	$12 455 310	$ 79 866 000	$36 158 720	$ 1 671 600	$281 766 120
Flood Control															
Avg Annual Loss 75% Benefits	$ 23 400 000	$ 1 560 000	$ 780 000	$ 5 070 000	$ 585 000	$ 1 950 000	$ 3 900 000	$ 1 365 000	$ 6 630 000	$ 10 920 000	$ 195 000	$ 3 705 000	$ 136 500	$ 390 000	
Flood Total Benefits	$ 18 500 000	$12 000 000	$ 6 000 000	$39 000 000	$ 4 500 000	$14 000 000	$30 000 000	$10 500 000	$51 000 000	$ 84 000 000	$ 1 500 000	$ 28 500 000	$ 1 000 000	$ 5 000 000	$305 500 000
Recreation Navigation															
Reserve Store (ac/ft)	18 500 000	1 400 000	350 000	2 600 000	3 800 000	6 300 000	6 800 000	150 000	12 200 000	78 700 000	500 000	8 400 000	63 800 000	8 200	
Population	5 637 000	650 000	8 374	47 962	12 910 000	10 752 000	8 016 000	7 255 000	30 006 000	8 614 000	1 162 000	18 918 000	5 646	29 220 000	
Benefits	$ 305 000	$ 2 700	$ 8 450	$ 365 000	$ 145 000	$ 199 000	$ 160 000	$ 9 600	$ 1 080 000	$ 2 010 000	$ 2 50	$ 467 000	$ 1 050 000	$ 702 000	$ 6 505 900
Other Benefits			-		-	-		--	-	-					
TOTAL BENEFITS	$ 86 148 000	$12 453 700	$17 167 550	$45 289 120	$ 7 911 780	$57 270 250	$41 226,100	$12 680,540	$61 648500	$148 847700	$14 706 260	$124 107600	$47 394 480	$11 011 900	$687 894 180

J Information Alternatives

An obvious alternative to information gathering by satellite is by aircraft equipped with proper sensing equipment Almost any aircraft large enough to accommodate a few hundred pounds of sensor equipment could be a candidate for the information-gathering mission The discussion in the Appendix, on satellite and alternative system costs, compares the cost/performance of three classes of aircraft suitable for use as alternative systems to the satellite in the information-gathering role The aircraft in the comparison are as follows

- The U-3, a relatively inexpensive, slow, and low-flying aircraft
- The SR-71, a very expensive, fast, and high-flying aircraft
- The T-39, a moderately expensive, moderately fast, and moderately high-flying aircraft

Each of the aircraft tested was chosen to be representative of a class of aircraft The "optimum" aircraft for the NASA missions is the middle-class aircraft, represented by the T-39 The T-39 is a swept-wing, twin-turbojet configuration used commercially as an executive transport aircraft, and by both the U S Air Force and Navy as a trainer The T-39's cruising speed is approximately 500 mph, with a service ceiling of about 42,000 feet and a range of 2,000 miles Using a sensor viewing angle of 120°, the T-39 has a swath width of 23 6 miles for the hydrology mission Assuming a flying-hour program of 60 hours per month, the T-39 can cover 708,000 square miles per month To perform the hydrology mission for the Columbia River Basin at a 6-hour observation frequency would require approximately 53 T-39 aircraft This figure is calculated as follows·

$$\frac{\text{(area of the Basin) (coverage per month)}}{\text{coverage per T-39 per month}} = \text{number of aircraft}$$

Substituting the known values

$$\frac{\text{(312,000 sq mi) (4 observ /day x 30 days)}}{\text{708,000 sq mi}} = \text{53 aircraft}$$

The total systems cost of these aircraft, including ground data analysis and interpretation costs, is approximately $780 million However, comparison of the aircraft system (or any other nonsatellite information system) with the satellite system for the hydrology mission in the Columbia River Basin solely excludes the benefit growth potential of the satellite system As discussed in another section of the report, potential benefits can accrue to the satellite system from hydrology applications in other areas of the United States (e g , Central Valley, California, Connecticut Valley, etc) and eventually in other areas of the world (e g , countries generating hydroelectric power) While hydrology applications to other areas beyond the Columbia River Basin can be thought of as a free good for the satellite system, new aircraft systems must be utilized for further applications at the same level of performance [1]

The economics of comparison among satellite and other information systems is most sensitive to the area to which each system is to be applied Exhibit II-55 illustrates the sensitivity of total system costs to area coverage for competing information systems It is clear that for areas as small as the Columbia River Basin (about 350,000 sq mi), a competitive nonsatellite information system is preferable However, as more applications of the satellite system are considered, and greater areas are to be viewed, the satellite system becomes the better competitor with the aircraft system having the same level of performance and reaches a crossover point at about one million square miles It is estimated that potential hydrology application in the United States alone would involve an area of about 1 6 million square miles Clearly, the satellite system is preferable at this level of performance

When considering worldwide application, it is probable that the cost curve will rise at the same rate for developed countries A

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[1] The ground costs (i e , ground receiving station, analysis centers, etc) of the satellite system will undoubtedly increase with application to additional areas However, these costs are insignificant relative to the major investment in the basic satellite constellation and launch vehicles

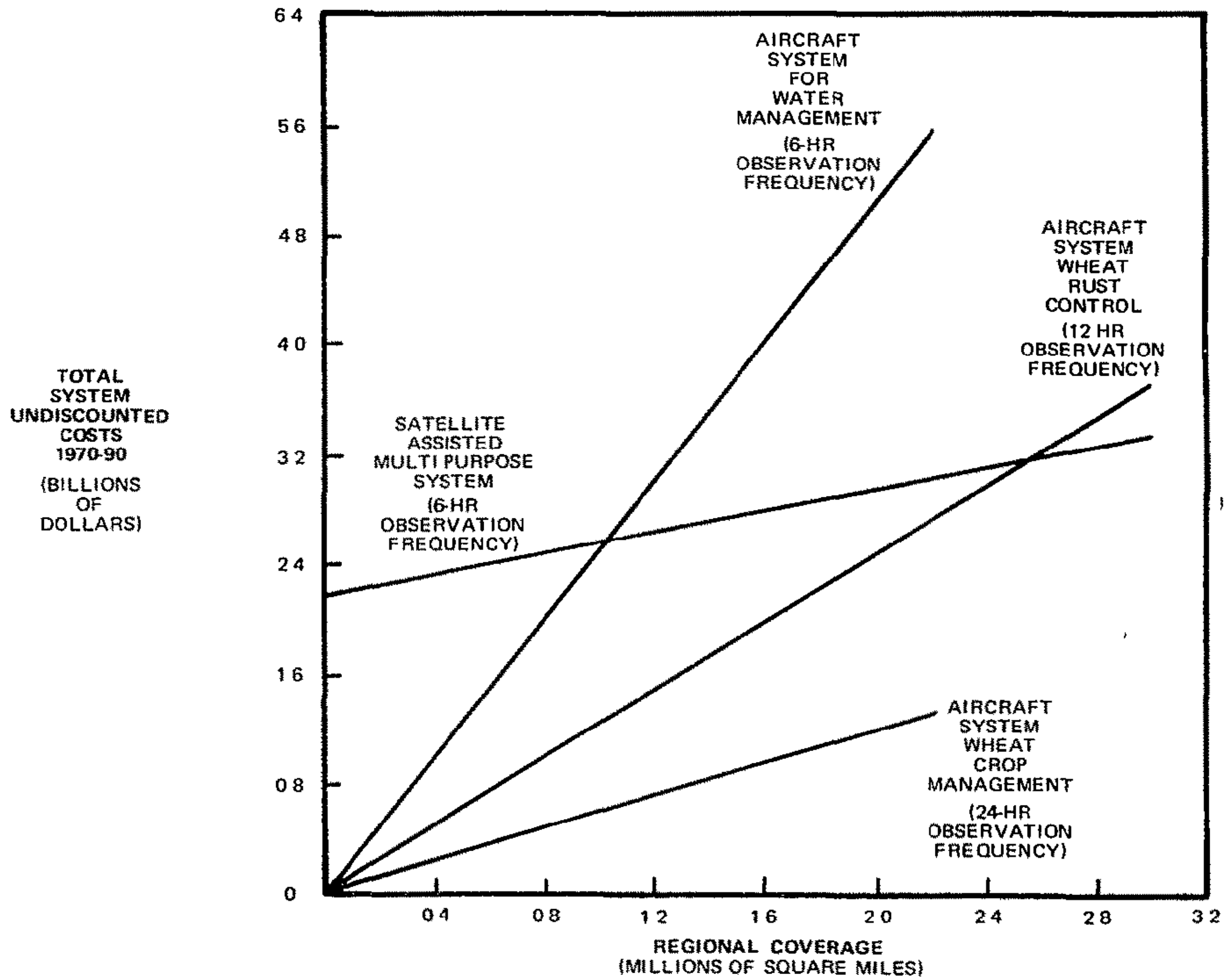


EXHIBIT II-55 SATELLITE AND AIRCRAFT SYSTEM COST/ PERFORMANCE COMPARISON (HYDROLOGY)

steeper rise can be expected in the case of underdeveloped countries, and costs would approach infinity for Russia and Red China

The previous discussion has addressed the competing information systems on the individual merits of hydrology applications Full satellite system costs have been presented, and no weight has been attributed to the multipurpose application potential of the satellite system When further consideration is given to the benefits of agricultural applications (and potentially, geological and oceanographic application areas) for which new aircraft systems costs would be incurred, the satellite system becomes an even better competitor

K Noninformation Alternatives

In this subsection of the report, the satellite-assisted information system is compared on a cost-benefit basis with water management programs which do not depend on improved information The satellite-assisted information system has been compared above with alternative means of gathering similar types of data For the satellite-assisted information system to be preferred, it must be superior not only to information alternatives but also to marginal noninformation alternatives being planned over the coming 20-year period

A number of potential projects in the Columbia River Basin area are under active consideration For the purposes of this analysis, several potential hydroelectric projects have been grouped as they would contribute to logical development of the area These are combined with potential irrigation projects in the same areas to provide a selection of noninformation alternatives ranging from more marginal new-project alternatives in remote areas to less marginal incremental-project alternatives at existing sites Clearly, the satellite information system should be superior to the marginal new-project alternatives and, at least, comparable to incremental-project alternatives

Five area development alternatives composed of several Federal projects were selected to provide a range of alternatives for comparative analysis·

Alt No 1	Flathead River Development
Alt No 2	Snake River Power Development
Alt No 3	Upper Snake River Development
Alt No 4	Southwest Idaho Water Development
Alt No 5	Columbia River Basin Power Additions

Generally speaking, each alternative is composed of varying elements of potential and/or authorized (but not under construction) Federal power and irrigation projects and, hence, represent important pending decisions Benefits from other project features such as navigation, flood control, and recreation are relatively minor for the range of alternatives considered in this analysis and are not included, nor are the specific costs and allocations of joint costs for these features included in cost-benefit calculations

Several cost-benefit summarization techniques are available to make the comparison between noninformation and satellite alternatives more equitable The summarization methodology employed in this analysis is to continue the use of the 1990 cutoff date and to estimate the market value of assets at the cutoff date, in current dollars, and add these values to the benefit streams of noninformation alternatives Costs and benefits for the 1970-1990 period would then be discounted to present worth This methodology estimates the need for projecting beyond 1990 but introduces the problem of estimating asset market values in 1990 either by some arbitrary depreciation method or from some predictive method based on historical data Nevertheless, this methodology is deemed preferable to those requiring projections beyond the 1990 cutoff period

Noninformation alternative costs and benefits are summarized in Exhibit II-56 The overall scope of each alternative in terms of power development (thousands of kilowatts of installed capacity) and irrigation development (thousands of irrigable acres for full and supplemental service) is included Also given are total alternative costs and benefits (excluding remaining asset values in 1990), at a zero-percent discount rate and at discount rates of 7 5, 10 0, and 12 5 percent Also indicated are the undiscounted remaining asset values for each alternative in 1990 assuming a useful asset lifetime of 50 years subject to straight-line depreciation Further details of each alternative are provided in the satellite and alternative systems cost subsections of the Appendix

The importance of considering remaining asset values is highlighted in the undiscounted cost-benefit ratios with and without remaining values attributed to each alternative in 1990 Without remaining asset values considered, only alternative Nos 1 and 2 would be judged better than marginal (i e , cost-benefit ratio 1 0) at a zero-percent discount rate With remaining asset values considered, all alternatives, except the Flathead River Development, are better than marginal at a zero-percent discount rate The order of preference for each alternative does not change with discounting, however, each alternative becomes less favorable with increasing discount rates as more weight is attributed

4

EXHIBIT II-56 NONINFORMATION ALTERNATIVES - CHARACTERISTICS AND COSTS TO 1990 (In Millions of Dollars)

		Alt No 1	Alt No 2	Alt No 3	Alt No 4	Alt No 5
Power (Thousands of Kilowatts Installed Capacity)		822 0	3,790 0	427 0	571 0	3,116 0
Irrigable Acreage for Service (Full 000's)		150 0	-	197 5	489 0	-
	(Supplemental 000's)	-	-	228 6	61 9	-
Total Costs Undiscounted		633 4	946 0	517 6	865 5	663 1
• Investigation and Planning		(35 2)	(48 9)	(27 4)	(47 0)	(31 5)
• Investment		(541 8)	(753 0)	(422 3)	(722 6)	(484 1)
• Operations and Maintenance		(40 8)	(128 9)	(55 7)	(75 0)	(133 4)
• General Expenses and Administration		(15 6)	(15 2)	(12 2)	(20 9)	(14 1)
Total Costs Discounted	7-1/2%	351 3	530 5	335 0	514 0	407 0
	10%	294 7	450 0	295 4	441 8	356 5
	12-1/2%	249 5	386 1	262 6	383 4	316 0
Total Benefits Undiscounted		166 8	544 0	695 6	969 0	618 5
• Power		(73 8)	(544 0)	(58 3)	(63 1)	(618 5)
• Irrigation		(93 0)	-	(637 3)	(905 9)	-
Total Benefits Discounted	7-1/2%	61 9	186 5	276 6	383 0	246 3
	10%	46 1	134 5	210 8	291 4	188 3
	12-1/2%	34 8	98 3	163 3	225 3	146 5
Remaining Asset Values 1990 (straight-line depreciation - 50 year lifetime)		422 8	572 3	304 2	549 1	338 9
Undiscounted B/C Ratio	(No Remaining Values)	0 26	0 58	1 34	1 12	0 93
	(With Remaining Values)	0 93	1 18	1 93	1 75	1 44
Discounted B/C Ratio	(No Remaining Values)	0 18	0 35	0 83	0 75	0 61
7-1/2 percent	(With Remaining Values)	0 46	0 61	1 04	1 00	0 80
	(No Remaining Values)	0 16	0 30	0 71	0 66	0 53
10 percent	(With Remaining Values)	0 37	0 49	0 87	0 84	0 67
	(No Remaining Values)	0 14	0 25	0 62	0 59	0 46
12-1/2 percent	(With Remaining Values)	0 30	0 40	0 73	0 72	0 57

to time differences in cost and benefit streams Thus, given the assumptions and factors used to develop cost and benefit streams, only the Snake River alternatives are judged better than marginal at a minimum attractive rate of return of 7 5 percent, even when including remaining asset values

The Snake River irrigation development alternatives (Nos 3 and 4) are judged to be about equal in preference and superior to the power development alternatives (Nos 1, 2, and 5) However, among the power development alternatives, the ranking is quite clear Alternative No 5, which consists entirely of power additions to existing dam sites, is preferred over new power projects (alternative Nos 1 and 2) Between the new-project power development alternatives, the larger and, hence, more efficient Snake River Power Development alternative is preferred over the smaller and more remote Flathead River Development alternative

The Flathead River Development (alternative No 1) consists primarily of new power projects as well as some new irrigation development in western Montana The Snake River Power Development (alternative No 2) consists entirely of new power projects along the mid-Snake River area, of which the often discussed Appaloosa (or High Mountain Sheep) project is the principal element Alternative Nos 1 and 2, consisting of entirely new projects, are expected, a priori, to be representative of more marginal noninformation alternatives being planned for activation in the next 20-year period Alternative Nos 3 and 4 represent continuing Federal irrigation and power development of the Snake River in southern Idaho and adjoining areas of Wyoming and Oregon, respectively These two alternatives consist of many new, relatively small power and irrigation projects with some additions to existing projects Hence, they are representative of somewhat less marginal noninformation alternatives than are alternative Nos 1 and 2 The Columbia River Basin Power Additions (alternative No 5) consists solely of power additions to several existing multipurpose projects in the Columbia River Basin and is expected to be the least marginal noninformation alternative from the range of alternatives offered

The typical noninformation alternative project assets involve high initial investment costs and low operating costs with useful lifetimes of 50 years or more The satellite system, by contrast, involves a relatively low but continuing investment in spacecraft with about 2- to 3-year lifetimes in order to realize continuing benefits Thus, the arbitrary 1990 cutoff time gives a zero value to the remaining useful lifetimes of noninformation alternative assets (e g , the capability to generate power for several more decades), assuming that costs and benefits cease for the satellite system with little or no penalty In other words, a cost-benefit ratio for the satellite system would show relatively little improvement as the cutoff date is extended to the year 2000 and beyond as compared to the noninformation alternatives, whose cost-benefit ratios would show significant improvement as the cutoff date is extended

In conclusion, the best ratio for the noninformation alternatives available in the Northwest is 1 04 when discounting is applied, and under the same discounting the satellite-assisted system shows a 1 2 ratio Most of the other noninformation alternatives are well below the 1 04 ratio

III AGRICULTURE CASES

The second major area analyzed in this report is agriculture The discussion is somewhat shorter than the water management case primarily because much of the matter developed in the earlier case is also applicable here It will be seen that the same sensor package is appropriate, the same satellite constellation can be used if desirable, and a very similar overall information system can be used The users are, of course, quite different, as are the user sensor and user decision models Although there was no attempt to analyze cases that supported a simpler satellite-assisted information system, it is apparent that a multipurpose system is emerging with economy in costs and modernization of benefits

A Information User Survey

In the agriculture case, two separate aspects of wheat were investigated wheat inventory/yield and wheat rust Since there is obviously a close interrelationship between the two, the discussion of the information systems has been combined where necessary for clarity To set the stage, the organizations, public and private, most interested in the system will be delineated and their relationships to one another discussed in general terms

Following the information user survey a joint user sensor model is presented The subsequent section on the user decision models, total benefits, total costs, sensitivity findings, information alternative, and noninformation alternatives are treated separately for the wheat inventory/yield and wheat rust cases

As shown in Exhibit III-1, the organization in the United States most involved in all aspects of wheat is the Department of Agriculture (USDA) Included here are the bulk of the monitoring, analysis, and reporting groups observing worldwide wheat production Data collection and crop projection are handled primarily by USDA's Statistical Reporting Service (SRS), Economic Research Service (ERS), and Foreign Agricultural Service (FAS) Both wheat yield and wheat rust are monitored

in USDA Other groups are involved in the system such as agencies of foreign governments, universities and colleges, commercial wheat enterprises, and wheat producers USDA, however, is at the center of the system and must be considered the primary decision point for agricultural monitoring, analysis, planning, and direction in the United States

Global wheat information currently is collected and disseminated basically by three systems international organizations, federal governments, and private grain interests

The United Nation's Food and Agricultural Organization (FAO) and the International Wheat Council (IWC) collect historical data as well as forecast world production Most of the data are supplied by member countries and through the cooperation of nonmembers Results of the analysis are distributed to member nations and also made available to any interested party through a number of official publications

The FAO generates a short-term market prospect analyzed on the basis of current or expected yield, known demand, and existing trade agreements Their long-term projections assume a certain political and economic environment in calculating the 10-year outlook. A program is presently being established by FAO to generate a medium-term projection combining the elements of short-term supply and demand and long-range policy.

For the past 10 years the IWC has projected supplies and closing stocks in eight exporting countries, and production and imports by regions of the world. However, its annual review is released in late fall, which limits the usefulness of the projection in marketing and production planning

The United States, through USDA, generates quarterly wheat situation reports and an annual outlook projection for wheat Global information is submitted through Foreign Agricultural Service attache reports four times yearly and by special reports of intervening events Host country information is obtained through personal observation, foreign government statistics, news releases, trade journals, and marketing representatives U S domestic information is collected by state statistical reporting services Analysis of the domestic and world wheat situation by the Economic Research Service (ERS) provides the basis for the global outlook projection and the annual wheat acre allotment.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

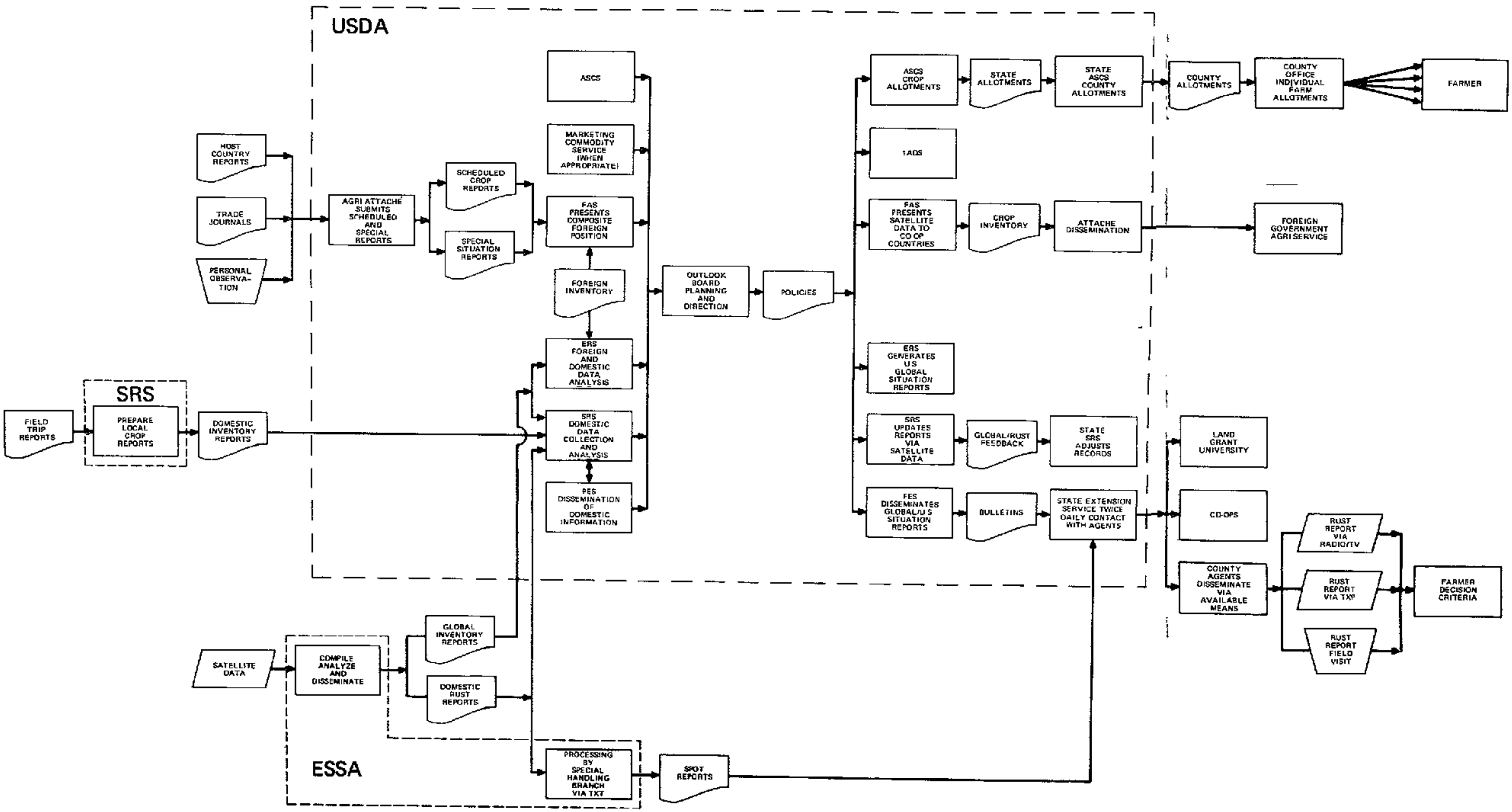


EXHIBIT III-1 WHEAT INFORMATION FLOW CHART

Grain exporters in the United States have extensive data collection information systems within their individual companies Although reports are market oriented, grain companies extensively review world production projections. Information is collected by and through the same sources available to the FAS, plus through development of their own contacts in host country grain interests. Reports issued by grain exporters do not conform to any schedule, but generally do precede USDA outlook reports, which are used by exporters to supplement commercial grain projections.

In the rust area, USDA, in conjunction with the University of Minnesota at the Cooperative Rust Laboratory, cites domestic wheat rust statistics in the April to June issue of the Plant Disease Reporter. State agricultural universities and university-sponsored research laboratories are used for data collection and to support the program. An industry-sponsored group, the Crop Quality Council, composed of scientists and agricultural experts, also collects and publishes domestic rust information. On the local level, the State Extension Services, with the cooperation of county agents and universities, propagate qualitative rust information, but with emphasis on proper variety planting as opposed to rust tracking and reporting on the degree of damage to the wheat crop

In summary, the information system, as it exists in both the wheat production and wheat rust areas, is highly dependent on published material, and requires a long lead time in order to gather the needed information through ground surveys.

Before designing an information system that will take advantage of data acquisition by satellite sensors, it was considered necessary to develop a body of expert opinion regarding the usefulness of faster and more accurate data to the agricultural community Exhibit III-2 shows, in tabular question-and-answer form, the results of the user information survey The sample of wheat interests listed at the top of the table is in no way intended to be statistically appropriate. It is intended, however, to cut across the spectrum of wheat interests so that a reasonable foundation of opinion from interested professionals could be obtained. Although USDA is listed only once, several highly placed members of this organization were interviewed, and their opinions were included in the summary.

WHEAT INTERESTS

Continental Grain Company
Cook & Company
Food and Agriculture Organization of the United Nations
Freightforwarders Institute
Grain and Feed Dealers National Association
National Council of Farmer Cooperatives
National Wheat Growers Association
United States Department of Agriculture

Q WHAT WHEAT INFORMATION IS NOW RECEIVED AND/OR GENERATED?

A. In addition to USDA-generated reports and bulletins from SRS and FAS submittals agribusiness concerns produce and/or receive world harvest projections and marketing demand reports from all major wheat importing sites Harvest projections are tabulated from observations on extent of seeding through growth until harvest.

Q WHEAT INFORMATION IS RECEIVED THROUGH WHAT CHANNELS OR AS A RESULT OF WHAT PROCESS?

A USDA receives scheduled and special reports from FAS attachés on their host countries The SRS purveys extensive statistical coverage of domestic production
Industry employs foreign agricultural research survey agents marketing representatives foreign governments' reports and Reuters Wire Service to obtain intelligence on the world wheat situation

Q IS THE INFORMATION RECEIVED/GENERATED ADEQUATE FOR THE DECISIONMAKER? IF NOT WHAT ADDITIONAL INFORMATION IS NEEDED?

A Although domestic yield predictions are very reliable some estimates of world production are assigned a low level of confidence Since the grain market is sensitive to supply and the U S has assumed the role as the deficiency buffer much refined information is needed on Russia China Soviet block countries Pakistan, India and even Australia and Argentina

Q WHAT ARE THE TIME REQUIREMENTS FOR WHEAT INFORMATION RECEIVED?

A The USDA outlook board's projection is normally released after the need for the requirement in agribusiness planning which is usually the first part of the second quarter Interindustry channels update projections of yield of the various countries of interest immediately upon receipt of any new applicable data Duplication by industry of a total world projection is released by early May if it is produced at all

Q WHAT SHOULD DISSEMINATION PROCEDURES BE FOR A SATELLITE ASSISTED SYSTEM?

A It is generally agreed that for the U S to retain its present role in the world wheat market and to prevent unfair advantage by any domestic merchant the USDA should remain the recipient and disseminator of satellite information

Q WOULD MORE ACCURATE TIMELY INFORMATION BE USED TO MANAGE WHEAT OR RELATED PRODUCTION? HOW?

A Reduction of wheat projection errors will result in a more efficient stable market USDA wheat acre allotments will be more consistent with world demand for U S wheat which could also result in a reduction of CCC stocks The scheduling of exporter owned merchant shipping could be smoothed out by an anticipation of probable sales Also grain merchants could present earlier quotations focus attention on certain classes of wheat and reduce the risk of inaccurate blending and co-mingling

Q WHAT DEGREE OF RISK DOES THE DECISIONMAKER ASSIGN TO DECISIONS WITH CURRENT INFORMATION?

A No risk is assigned per se to information obtained from a questionable source Each country's projection is adjusted within the range of past performance based on actual data In long range planning risk is assigned to decisions governing the investment of funds into capital projects in lesser developed countries Some thought is also given to the possibility of PL 480 recipients eventually becoming commercial buyers

Q WHAT RUST INFORMATION IS NOW RECEIVED AND THROUGH WHAT CHANNELS?

A Very little current rust information is disseminated to the wheat farmers County Agents from the State Extension Service and cooperative newsletters present, in generalized form geographic disposition of rust infection and spore movement,

Q IS RUST INFORMATION ADEQUATE AND IF NOT WHAT ADDITIONAL INFORMATION IS REQUIRED?

A Certain varieties of wheat are more or less resistant to certain strains of rust General rust information now produced does not always classify the dominant strain of rust infecting a given area Spore movement is dependent on weather and very little localized forecasting of wind and shower conditions is made available Also very little information is generally generated concerning the extent of rust damage after infection

Q WHAT ARE THE DECISION POINTS RELATIVE TO RUST PROBLEMS?

A. Any decision to act in combating wheat losses due to rust must account for the probability of spore fallout and the degree of infection Even with the lack of economical protectant fungicide sprays, better tracking of rust movement might lead to proper variety planting,

EXHIBIT III-2 SUMMARY OF USER INFORMATION SURVEY

Two points of major interest were revealed by the survey First is the conclusion that more accurate and timely information would result in a reduction of wheat projection errors and, thus, in a more efficient and stable market This is particularly important to the Commodity Credit Corporation (CCC). USDA wheat acre allotments will be more consistent with world demand for wheat, probably resulting in a reduction in CCC stocks The second important finding deals with rust Very little information is currently disseminated to wheat farmers. An information system that provides accurate, timely data on the movement and degree of rust infection will give the wheat producer the option, now unexercised, of adopting the spray techniques

Under the current system, a four step model which considers consumption, current stocks, exports, and production is used by USDA to determine wheat acreage allotments Consideration was given to using this model as a basis for developing benefits in the area of wheat production. The original study concept, however, was not oriented toward estimating wheat acreage allocation alone. Instead, it was intended to describe the manner in which the satellite-supported system can assist planners in effectively allocating resources for wheat production. The satellite system conceptualized in the study is an information system intended to give USDA decisionmakers better information for a variety of policy issues, not only wheat acreage allocations As a corollary problem, it is evident that adaption of an operational system such as this undoubtedly will require reappraisal of major policy and legislative issues. One example might be the frequency with which acreage allocations are revised through the growing season No attempt was made to adjust the findings of the study to possible legislative or policy changes. Besides being well outside the scope of the research effort as delineated by the ERSPRC, a study of legislative implications would have required an inordinate amount of political speculation The assumption was made, therefore, that legislative and policy issues resulting from an operational satellite system could be resolved satisfactorily

B User-Sensor Model

The parameters requiring satellite sensing appear to be the following in the wheat inventory yield case

- Wheat recognition
- Plant emergency, location, and area
- Plant density, color, and temperature
- Plowed land
- Wheat harvesting
- Snow cover
- Soil moisture

These sensed parameters will be discussed in more detail under the user decision model and appropriate scenario

The sensed parameters for the wheat rust case include the following

- Areas with rust with greater than 25-percent severity
- Crop identification and stages of growth
- Temperature differences, plant versus ambient
- Rainfall areas
- Free moisture
- Soil moisture
- Cloud velocity

Again, these measures will be discussed in detail under the scenario described in the wheat rust case

The sensor package required for these two cases must be such as to give adequate frequency of observations and reasonable reaction time from date of collection to the time information is available to the users In the wheat rust case it will be seen that 12-hour coverage is required and in the inventory/yield case a 3-day coverage is adequate

The process for selecting the sensor package and satellite constellation was to compare the availability of data from the water management configuration and determine whether it is adequate for the wheat inventory/yield and wheat rust cases The sensed parameters can be observed by the MSS, TV and radar package defined under the water management case All three are critical for the wheat rust case In

the wheat inventory/yield case it is conceivable that ground data can be substituted for the radar, however, given very poor meteorological data from ground stations for overseas wheat growing areas, the radar should be retained for maximum accuracy in estimating overseas wheat production

The Appendix G gives some further information on agricultural data collection techniques The subsection entitled, "Interpretation of Agricultural Data" includes a description of the feasibility of detecting and identifying wheat fields from aircraft and/or spacecraft using an MSS

After establishing the appropriate sensor package, the discussion of the wheat inventory/yield case will deal with the forecasting techniques required and the user management techniques, to give the reader an introductory overview of the system A system dependency matrix (Exhibit III-3) has been prepared to integrate the sensors, forecasts, and user decision model The lower right corner matrix illustrates which sensor observations could contribute to the various physical measurements such as crop identification, crop area, stress identification, etc In the lower left matrix, the numbers in the cells indicate the degree to which the physical measurements contribute to the forecasting The number 1 means that the physical measurement is sufficient to make the forecast possible. The number 4 means that the physical measurement makes slight to no contribution to the forecast The number 2 signifies a major contribution and 3 some contribution In several instances, where two numbers appear in a cell, the value of the physical measurement to the forecast, for example, lies between the two values Similar numerical ratings are used in all three matrices The forecasting elements contribute to the management areas/benefits at the top of the matrix in much the same manner

EXHIBIT III-3 WHEAT INVENTORY - EARLY OPERATIONAL SYSTEM

MANAGEMENT AREAS/BENEFITS	Crop Identification	Crop Area and Location	Stress Identification	Stress Severity	Stress Location	Stage of Growth	Ground Conditions	Weather
1 CCC Savings	2	2	2	2	2	2	2	2
2 Producers Options	2	2	3	2	2	2	2	2
3 Lower Unit Costs	2	2	2	2	2	2	2	2
4 Agribusiness Savings	4	4	3	3	2	4	3	2
5 Lower U S Foreign Assistance	2	2	2	2	2	2	2	2
6 Benefits in Lesser Developed Countries	2	2	2	2	2	2	2	2

FORECASTING

Crop Identification	Crop Area and Location	Stress Identification	Stress Severity	Stress Location	Stage of Growth	Ground Conditions	Weather	MEASUREMENTS	SENSORS TV	MSS	Radar	MWR	IR Scan
4	4	3	3	3	3	4	2	Minimum Daily Temperature	4	1 (H)	4	2 (A H)	1 (H)
4	4	3	3	3	3	3	2	Maximum Daily Temperature					
4	4	2	2	2	2	2	2	Rainfall	3 (B C I)	2 (B C I)	1/2 (B C I J)	2 (A B C I)	2 (B C I)
4	4	2	2	2	2	2	3	Soil Moisture	3 (B C)	2 (B C)	2 (B C)	2 (A B C)	2/3 (B C)
2	2	2	2	2	3	4	4	Plant Temperature	4	1 (AF)	4	3/4	1 (A)
3	3	2	2	2	2	4	4	Respiration	4	4	4	4	4
3	3	2	2	2	2	4	4	Evapotranspiration	4	2 (A K)	4	3/4 (A K)	2 (A K)
1	1	3	3	3	2	4	4	Acres of Wheat	2 (D G)	1	2 (D E)	3/4 (A)	2/3 (E)
4	4	3	2	3	2	4	4	Density (% ground covered by wheat)	2	2 (G)	2 (E) E	3/4 (A)	2/3 (E)
4	4	2	2	2	4	3	2	Wind (direction and velocity)	4	4	4	3/4	4

Legend

1 Sufficient
2 Major Contribution
3 Contribution
4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT III-3 (Continued)

A	Too low a spatial resolution
B	Can detect but not quantify
C	On the basis of area extent only
D	On the basis of low resolution shape information
E	Insufficient resolution for identification by shape and insufficient spectral information
F	Would be excellent if sufficient spatial resolution were possible
G	On the premise of spectral recognition
H	High frequency observation required
I	After fall of rain
J	During fall of rain at time of passage
K	Depending on time of diurnal cycle, transpiration controls plant temperature
L	Could detect wet versus dry soil
M	Could detect heavy rain
N	Obscured by clouds
O	Limited swath width
P	Thermal infrared channel
Q	Qualitative indication
R	Inference from cloud cover
S	Better resolution offers improvement
T	Better resolution would improve interpretability or discriminability
U	Improved discrimination, technique, accuracy, or interpretability

C Wheat Inventory/Yield Management

1. Wheat Inventory/Yield User Decision Model

a Current Production Situation

The world's current supply of wheat is being produced primarily by 47 nations that collectively harvest approximately 10 billion bushels each year. This harvest is derived from a total of 20.1 bushels per acre During the past decade, annual production has shown a relatively gradual growth of 200 million bushels per year This current 2 percent annual growth rate, however, has been overshadowed by average year-to-year fluctuations of approximately 830 million bushels, which represent over 8 percent of the current annual production, and are over four times the annual growth rate A change of over 1 billion bushels from the previous year has occurred in 5 of the last 10 years

The wide variations in annual world wheat production have been caused by an average annual fluctuation of 7.7 million in the number of harvested acres, and an average annual fluctuation of 1 2 bushels per acre in yield. These represent average annual variations of 1 5 percent and 6.0 percent of current levels of inventory and yield, respectively. Although the number of acres planted with wheat varies from year to year, the variance in harvested acres and in yield is due primarily to the effects of climatic conditions and production procedures. The more severe fluctuations in harvested bushels reflect the tendency of yield and inventory to vary in the same direction, not as random independent variables Yield and acreage have varied in the same direction in 8 of the last 10 years

In the United States, the annual wheat acreage allotment for the forthcoming crop year is based, to a large extent, on harvest forecasts for the current domestic and foreign crop. Estimates of the current domestic crop, together with onhand carryover stocks from the previous year, indicate quantities available for domestic utilization and export Harvest forecasts for foreign crops provide indications of world import requirements and trade competition from other exporting nations

Currently, over 20 percent of the world wheat production enters international export/import trade

To provide a better overview of world wheat production characteristics, Exhibit III-4 shows the 10 largest harvests of 1966 and identifies the relationship of this 1966 harvest to world gross and net exports and imports

b Need for Timely Production Information

The characteristic cyclic behavior of world wheat production and its causes preclude effective harvest forecasts without comprehensive timely information concerning the quantity and quality of wheat actually being cultivated throughout the world The current need for this timely production information is also apparent from the current balance of international net exports and imports

Exhibit III-5 shows that in 1966 the United States, Canada, and Australia alone accounted for almost 90 percent of the total world net exports of wheat, while the Soviet Union appears statistically as a relatively minor net importer The total production of the Soviet Union, however, was approximately 20 percent larger than the combined production of these three largest net exporters If the yield of Soviet wheat were raised 6 bushels per acre, for example, to a level slightly below that of Romania (still less than that of United States and Canadian wheat), the Soviet Union could become the world's largest net exporter of wheat

These uncertainties, along with the precarious balance in international wheat trade, illustrate domestic difficulties associated with acreage allotment decisions in the United States and the significant potential impact on Commodity Credit Corporation (CCC) wheat operations since the United States exports approximately two-thirds of its annual domestic production

The need for timely production information is as critical, if not more so, in the less developed countries (LDC) of the world In LDC's, where the effort is to maximize foodgrain production, agriculture is the largest sector of their economies Because of limited resources and increased population, LDC's in recent years have shifted

EXHIBIT III-4 · TEN LARGEST WORLD WHEAT PRODUCERS (1966)

Rank	Country	Harvested Bushels (Millions)	Percent Of World Total	Cum Percent	Harvested Acres (Millions)	Average Yield (Bu/Acre)
1	Soviet Union	3,123	29.8	29.8	173.0	18.1
2	United States	1,312	12.5	42.3	49.9	26.3
3	Common Market	973	9.3	51.6	24.7	39.4
4	Canada	827	7.9	59.5	29.7	27.9
5	Red China	764	7.3	66.8	60.5	12.6
6	Australia	467	4.4	71.2	20.8	22.4
7	India	383	3.6	74.8	31.3	12.2
8	Turkey	301	2.9	77.7	17.7	17.0
9	Argentina	230	2.2	79.9	12.9	17.8
10	Romania	186	1.8	81.7	7.5	24.9
		8,566	81.7		427.0	20.0
	33 Others	1,924	18.3		94.0	20.5
	World Total	10,490	100.0		521.0	20.1

EXHIBIT III-5 INTERNATIONAL WHEAT TRADE (1966)

	Total 1966 Production	Gross				Net			
		Exports		Imports		Exports		Imports	
Net Exporters	M-Bu	M-Bu	%	M-Bu	%	M-Bu	%	M-Bu	%
1 United States	1,312	867	(38 7)	1	(0 1)	866	(47 8)	0	
2 Canada	827	581	(25 9)	0	(-)	581	(32 0)	0	
3 Australia	467	183	(8 2)	28	(1 2)	155	(8 6)	0	
4 Argentina	230	114	(5 0)	0	(-)	114	(6 3)	0	
5 Common Market	973	248	(11 1)	172	(7 7)	76	(4 2)	0	
6 Greece	72	21	(0 9)	0	(-)	21	(1 1)	0	
	3,881	2,014	(89 8)	201	(9 0)	1,813	(100 0)	0	
Net Importers									
Soviet Union	3,123	115	(5.1)	288	(12 9)	0		173	(9 5)
Free Developed	563	20	(0 9)	364	(16 2)	0		344	(19 0)
Other Communist	1,593	16	(0.7)	465	(20.8)	0		449	(24 8)
Free Less Developed	1,330	75	(3 5)	922	(41 1)	0		847	(46 2)
	6,609	226	(10 2)	2,039	(91 0)	0		1,813	(100 0)
World Total	10,490	2,240	(100)	2,240	(100)	1,813		1,813	

national plans to give more emphasis to agricultural rather than industrial development Timely production information allowing more accurate harvest forecasts can provide for more efficient allocation of resources and thus increase the rate of agricultural growth and gross domestic product (GDP) for the LDC's In turn, these improvements can provide more efficient returns from United States economic assistance programs

c System Concepts for Determining Annual Wheat Allotment Goals

For effective allocation of resources for the production of wheat, it is necessary that more accurate harvest information be available sooner to the appropriate decisionmaker A wheat production analysis system that combines satellite observation data with new analytical techniques can meet these requirements and provide significantly improved lead time for response actions.

Exhibit III-6 illustrates the potential improvement in forecasting capability by comparing the accuracy of current estimates of world wheat harvest with those that can be achieved by the satellite-assisted system Analysis indicates that at harvest (i e , by September 1) current world estimates are accurate to within ± 13 percent, and with the satellite-assisted system, this would probably be reduced to a tolerance of ± 2 percent In terms of 1966 production this means that the error in the September 1 estimate of the year's harvest can be reduced from ± 1,360 million bushels to ± 210 million bushels Analysis also indicates that an accuracy of ± 2 percent in world production estimates is not currently achieved until approximately 15 months after the world crop has been harvested (i e , December 1 of the subsequent year)

Because of high current capabilities for estimating domestic wheat production, it is expected that the improvement in domestic production estimates made at the time of harvest will not be as large as the potential improvement in world production estimates For comparative purposes, Exhibit III-7 illustrates potential harvest estimate accuracy improvements applicable to the United States wheat crop alone The differences between world and domestic estimates are clearly revealed in Exhibits III-6 and III-7 Current capability is approximately within ± 2 percent by September 1, and it is anticipated that the satellite-assisted

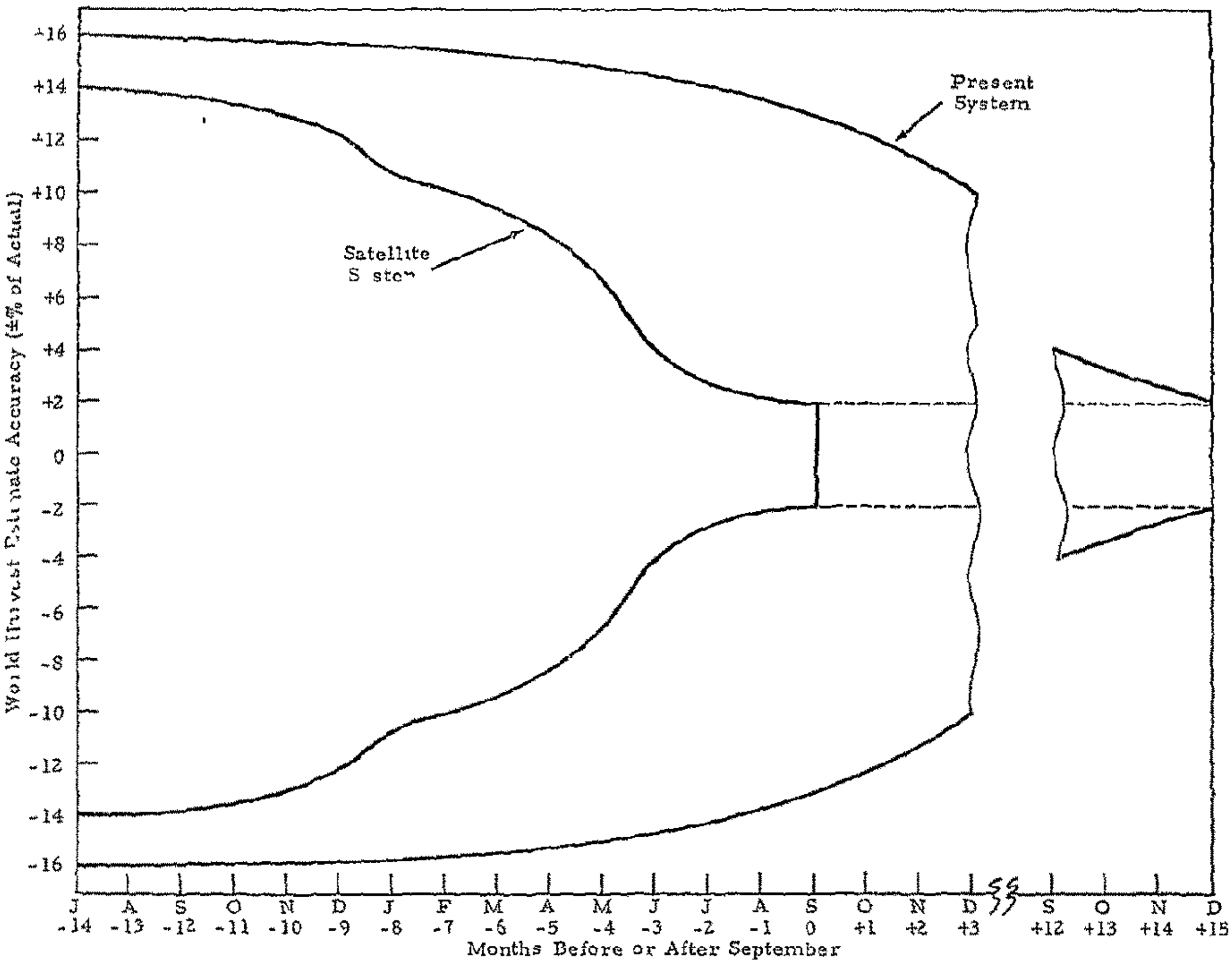


EXHIBIT III-6 POTENTIAL IMPROVEMENT IN WORLD WHEAT HARVEST ESTIMATES

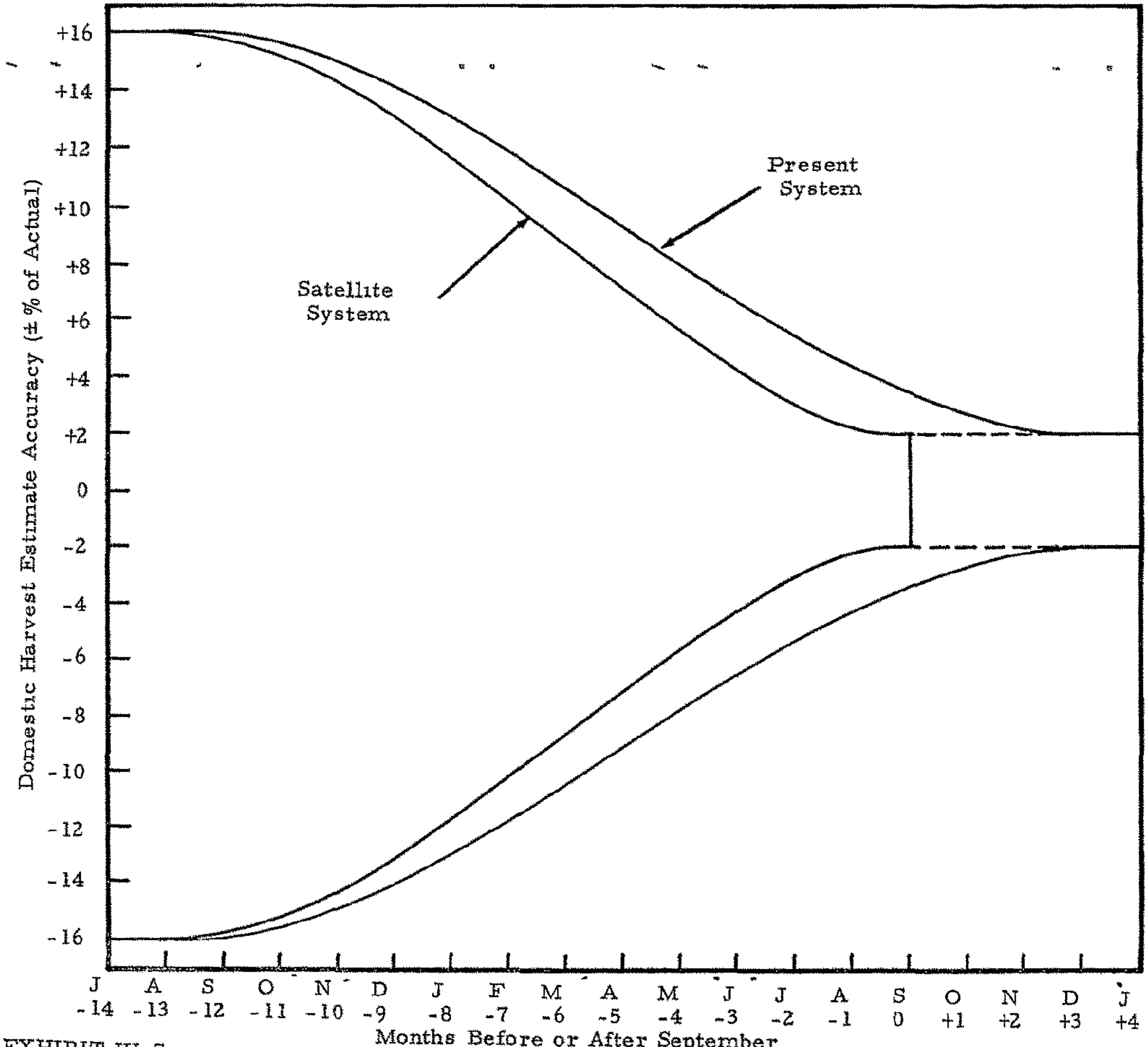


EXHIBIT III-7 POTENTIAL IMPROVEMENT IN DOMESTIC WHEAT HARVEST ESTIMATES

system will only reduce this to about ± 1 percent. For domestic production, the most significant contribution will be in the preharvest period. It is anticipated that the June 1 harvest estimate accuracy will be improved from ± 11 percent to ± 4 percent. In terms of 1966 production, this represents an accuracy improvements of 90 million bushels from approximately ± 140 million to ± 50 million bushels as of June 1. A detailed explanation of how these exhibits were derived can be found in Appendix H, Section I, User Decision Model.

The basic system concept is that of continually monitoring--by satellite, on a daily basis--production activities and environmental conditions in all wheat producing areas of the world between planting preparation and harvest These observed data would then be continually evaluated to provide forecasts of the estimated number of bushels to be subsequently harvested As the season progresses from planting to harvest, the forecast accuracy would continually improve, culminating with the most accurate values at harvest Following harvest, subsequent improvement in harvest estimates will be achieved by analysis of reported data, as at present

The functional organization of the wheat production analysis system is presented in Exhibit III-8 Although many of the satellite-observed factors have direct bearing on both inventory and yield evaluations, it is easier to derive concepts for operational requirements and procedures by treating each as a separate functional area These two are in turn delineated from a third functional area, namely, production or the harvest itself

The objective of the inventory status program of the system (see Exhibit III-8) is to monitor land areas throughout the world to determine where wheat is being produced, the number of acres under cultivation, and the variety and stage of growth of the wheat being produced In addition, the inventory status program would compare observed data with historical inventory file data to determine changes in location, acreage, and variety

The orientation of the yield analysis program is toward the quality and subsequent volume of wheat being produced The objective here is to provide localized forecasts of the anticipated yield (i e , bushels per acre) of wheat under cultivation throughout the world

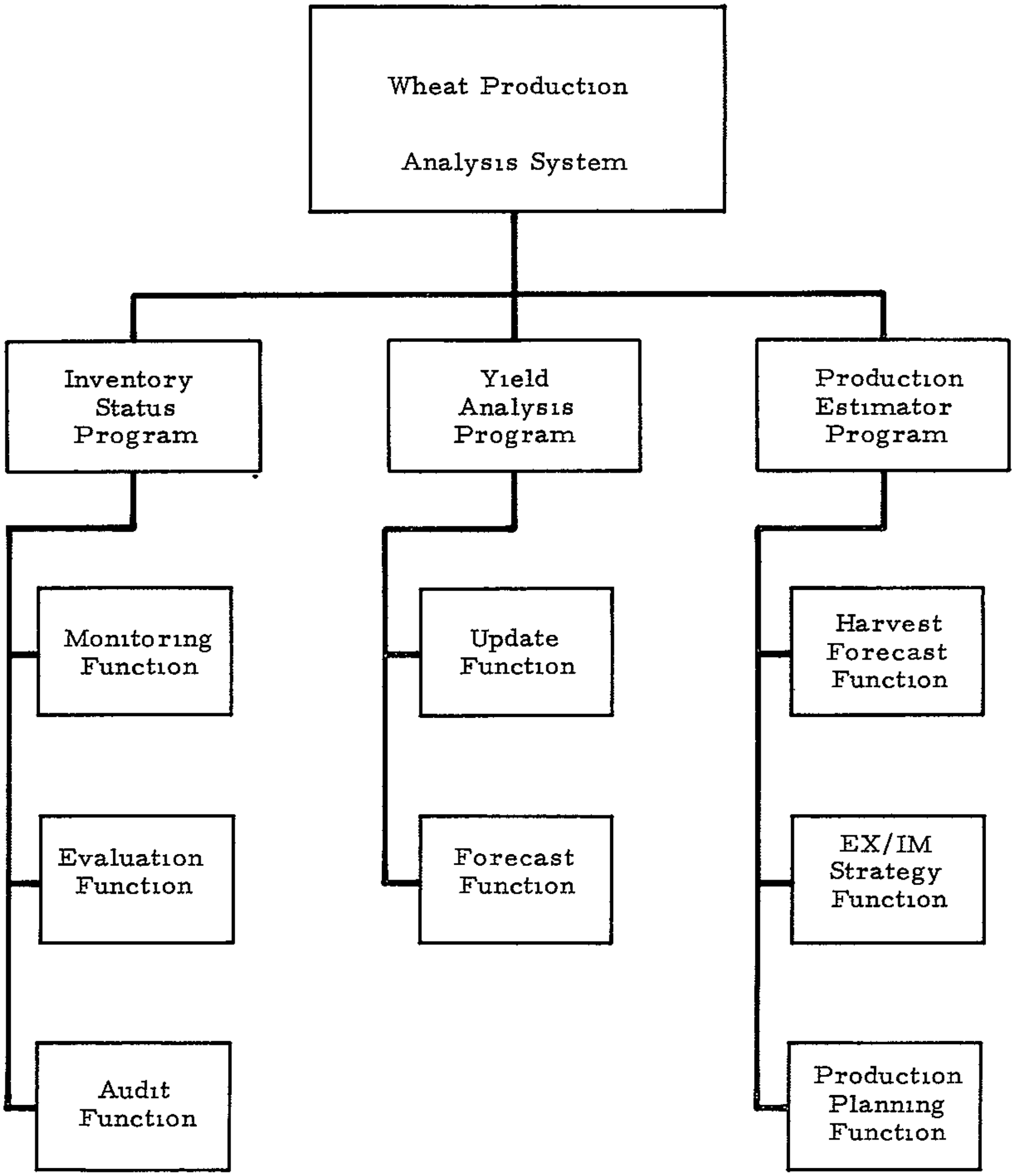


EXHIBIT III-8 FUNCTIONAL ORGANIZATION OF THE WHEAT PRODUCTION ANALYSIS SYSTEM

Observed temperature, soil moisture, precipitation, stress, vigor, and production operations would first be compared with historical values to establish reference levels for the current season These updated values would then be further modified to reflect anticipated levels forecasted for the time remaining until harvest

The third functional area (see Exhibit III-8) is related to the analysis of satellite-gathered data and their correlation to information available from other domestic and international reporting networks In addition to the preparation of local, regional, and national harvest forecasts, further analysis would be conducted to provide support to developing export/import strategy and policy, and to assist in the preparation of national and farmer production plans for the subsequent crop year

d System Concept for Midseason Adjustments

The unique capabilities of the satellite information system allow midseason adjustments in wheat acreage that have not, until now, been feasible With the United States performing a role of buffer in the world wheat market, the United States could make adjustments in the spring wheat planting allotments, given better knowledge about the amount planted and condition of winter wheat For example, the real possibility exists that spring wheat acreage could be adjusted upward to compensate for an unexpected decline in winter wheat acreage planted or adverse weather conditions and observed wheat vigor that would combine to reduce the winter wheat harvest

The basic system concept is nearly identical to that previously described in the annual allotment case It requires continual monitoring of the production activities and environmental conditions in all wheat-producing areas of the world beginning with seed-bed preparation in early fall The satellite capabilities and data collection requirements are identical

The significant changes in the total system are the additional elements involved in making spring acreage allotment changes operational These elements are physical, information, and other

(1) Physical Elements

The first principal factor is the magnitude of winter wheat production variations that would be offset by spring wheat changes The average annual world wheat fluctuation is 830 million bushels Since 70 percent of total world wheat production is winter wheat, it is assumed that 70 percent or 581 million bushels could be estimated as occurring in winter wheat areas This is larger than the average U S spring wheat production, which has averaged 244 million bushels over the last 10 years However, it is not unlikely that the U S spring wheat production could rise as high as 461 million bushels, based on average per-acre yields over the past 10 years and the potential spring wheat acreage of 22 4 million acres reached in 1951 Clearly, there is an unused potential U.S spring wheat yield of 217 million bushels that would offset nearly half of an estimated 581 million bushel potential world decrease in winter wheat production The residual adjustment might be made by overseas producers

The second principal factor is the likelihood that farmers would or could shift from other commodities to wheat Regression analysis on shifts in acres planted to principal crops showed that United States farmers do substitute rice, sorghum and millets, and other grains for wheat Therefore, it is likely that such shifts could be made, given a demonstrated need for acreage changes

The third principal factor is the magnitude of spring replanting of wheat that may occur No present estimates exist, but additional research could establish rates based on conditions of the winter wheat crop This factor would exist for other countries as well as the United States

The fourth factor involves the consumption substitutions of other commodities for wheat in times of wheat underproduction Income elasticities for wheat are negative in the developed countries of the world, meaning that as incomes rise, wheat consumption goes down On the other hand, the same countries generally increase wheat imports when domestic production goes down Less developed countries have positive income elasticities for wheat because they are continually improving their diets Some also show evidence of substituting wheat imports

for domestic wheat production, but others show more constantly increasing wheat imports, particularly India, Pakistan, and the U.A.R., because of their rapidly expanding, poorly fed populations. Clearly, these factors would have to be measured and evaluated in deciding whether or not, and how much, spring wheat allotments should be increased. Attempts to measure the relevant elasticities are explained in Appendix H.II, A Note on Substitution on Wheat Production and Consumption.

(2) Information Elements

Two principal information elements have to be defined One is the percent of error in estimating production that still exists in the satellite information system in late winter or early spring (February) when the wheat allotment adjustment decision has to be made In February, the present system estimates of harvest production could be in error by ± 16 percent With the satellite-assisted system, the error could be ± 10 percent (See Exhibit III-6)

After the introduction of the satellite-assisted information system by February, the continual inflow of information will make it possible to make an accurate estimate of the acres of winter wheat that will not be harvested because of winterkill There will also be data on the yield potential of remaining acres that will be harvested With this knowledge, the satellite-assisted system will make possible the reduction of estimation errors in world wheat production from ± 14 percent at planting time (September) to ± 10 percent in February (See Exhibit III-6)

At the present time, the amount of winter wheat acreage lost due to winterkill in proportion to the amount lost due to subsequent spring and summer meteorological factors is not known However, successive years of observation will give this parameter as well as improved projections of the yield on remaining acres.

The spring wheat acres adjustment need not be made solely on the basis of acres Elsewhere in this report is an analysis of the benefits accruing from the increased application of fertilizer made possible by improved weather forecasting of above-average rainfall This would permit adjustments in yield of both spring and remaining winter wheat, as well as acres of spring wheat in an effort to offset winter wheat losses

The other information element is the leadtime required for making the allotment decisions within USDA and allowing farmers to adjust their planting schedules The USDA adjustment decision would have to be made within an extremely short time frame, but the continuous inflow of satellite information will make it possible to more rapidly and accurately compute the spring wheat acreage changes Farmer leadtime would require a fast, effective information dissemination system and adequate stocks of seed

(3) Other Elements

The proposed system would require major policy changes in current commodity programs At present, the Secretary of Agriculture makes allotment decisions in June with increases in allotments possible until September The proposed system would additional upward adjustments be possible as late as February or March, just prior to spring wheat planting time Therefore, appropriate policy, and any necessary legal changes, would have to be made to allow the Department of Agriculture to make midseason changes in spring wheat allotments

e. Operational Procedures

The various observational requirements (sensor parameters) necessary for detecting those seasonal factors that affect the wheat inventory (acres) and wheat yield (bushels) are detailed in Appendix Exhibit H-7. For some seasonal factors, a direct observational requirement is either not sufficient or must be analyzed further. This is shown in the column entitled "Basis for Analysis."

The preparation of the ground in September and October, including plowing and harrowing, gives the first estimate of the area to be planted This is later verified by the emergence of the plants when in their early growth stages they are positively identified as wheat

The first estimates reported can be modified by analysis of the vigor and vitality (stunted or weak growth) of the plants entering winter Further refinements of the inventory and yield estimates can be made throughout the winter months by evaluating the effects of severe cold, strong winds, and the lack of snow Heaving, or the alternate freezing and thawing of the soil, can also reduce the acres and bushels of wheat to be harvested

By March and April, better estimates can be projected by evaluating the total effects of winter on the wheat crop, together with the replowing, plowing, and harrowing of land to be planted in spring wheat The verification of spring wheat among the spring crops which emerge in April and May is made by positive signature identification of wheat in the early growth stages

A critical factor in both the winter and spring wheat is the vigor and vitality of the plant in May through July Projections are refined, based on the quality of the wheat plants at this time and whether or not the various stages of growth are either behind or ahead of schedule Relative soil moisture, together with abnormal temperatures, also modifies the yield estimates Storm damages in summer can reduce the estimate of spring wheat that is about to be harvested

The sequential season factors are applicable in varying degrees to each individual wheat-producing area, with appropriate adjustments for differences in planting and harvesting schedules as they occur in the various parts of the world World wheat production estimates then are formulated by summing the individual estimates applicable for each area as of any given date

In reality, the composite world harvest estimate will be most influenced by three major categorizations of world wheat production (1) southern hemisphere winter wheat, (2) northern hemisphere winter wheat, and (3) northern hemisphere spring wheat These three categories are planted and harvested in sequential order with little overlap between categories This scheduling is illustrated in Exhibit III-9

Exhibit III-9 also shows that certain countries constitute the bulk of the production associated with each category Australia, for example, accounts for over half of the southern hemisphere production, and the Soviet Union, as another example, accounts for over half of the northern hemisphere spring wheat production

Thus, the progressive improvement in harvest forecast accuracy results from not only a sequence of seasonal factors associated with any given crop, but also a seasonal sequence of major crop categories

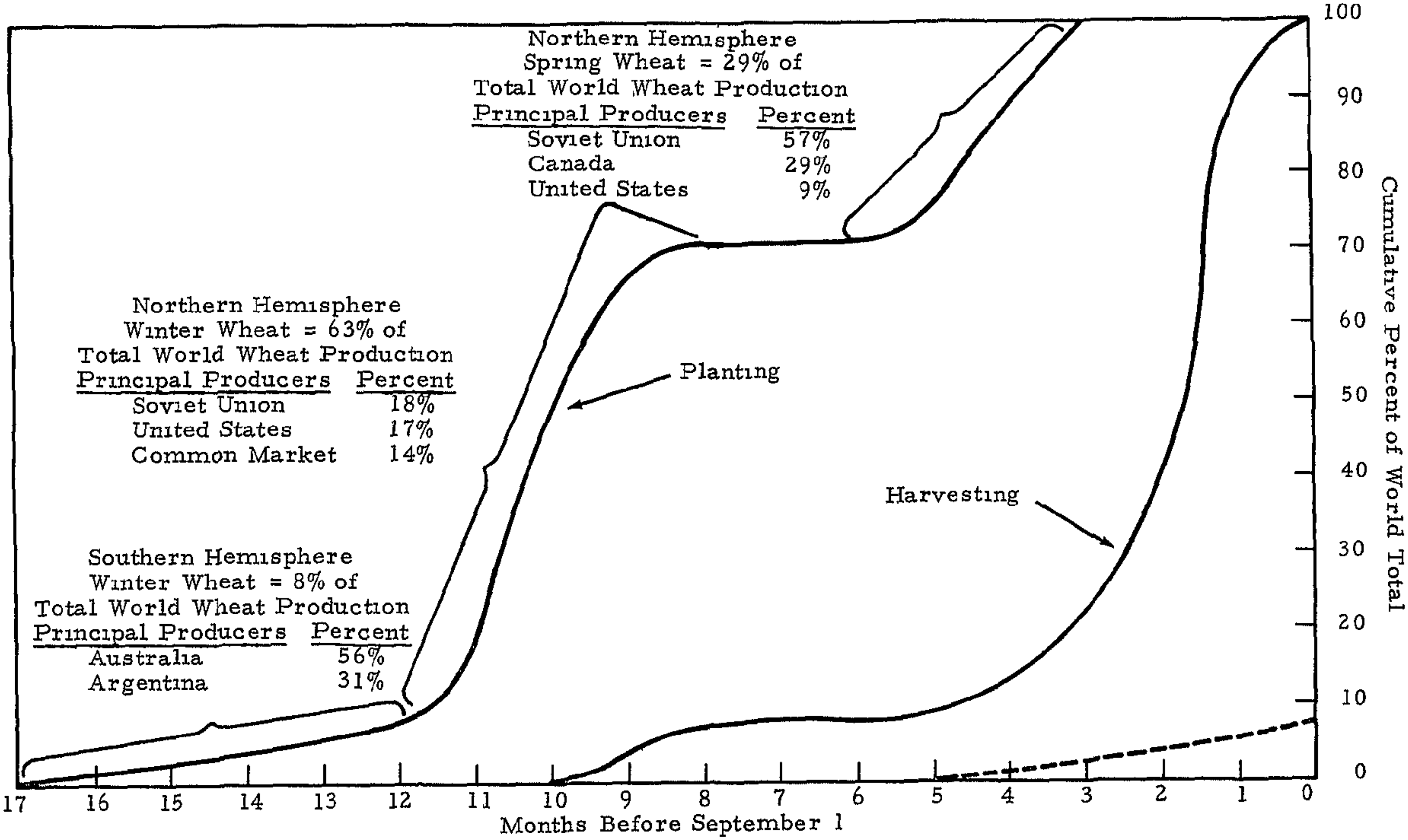


EXHIBIT III-9 ANNUAL WORLD WHEAT PLANTING AND HARVESTING SCHEDULES

To further understand the basis for the Observational Model, a scenario is presented in Appendix H.IV, "Wheat Production Analysis System Scenario." The purpose of the scenario is to illustrate more specifically the various "happenings" and subsequent causal factors that result in certain decisions made during a given crop year. This scenario includes several seasonal factors that influence the number of acres harvested and the yield at harvest.

There are six components in the wheat yield model as shown in Exhibit III-10 These components in determining wheat yield or bushels of wheat are

- Wheat areas
- Soil moisture
- Air temperature
- State of wheat growth
- Probable environmental conditions before harvest
- Probable wheat yield

Direct satellite sensing is required for all of the separate components except the "Probable Wheat Yield" and that requires an analysis of the interaction of all satellite sensings plus the necessary ground observations and historical information

The events abstracted from the Wheat Inventory and Yield Scenario are listed in chronological order on Exhibit III-11 This shows the relationship of events to the components of the model It should be noted that the various components within the United States do not really affect the decisionmaking process to any degree after June 1, at which time the allocation of wheat acreage for the next year is made by the U S Department of Agriculture Only confirmation is made of those factors already forecasted prior to June 1 International factors, based on supply and demand of wheat, determine whether the allocation of acreage is changed (increased) after this date

Exhibit III-12 shows the events by time periods as abstracted from the Wheat Inventory and Yield Scenario, together with the required number of sensings for each of the components of the wheat yield model

EXHIBIT III-10 WHEAT INVENTORY AND YIELD MODEL COMPONENTS AND SENSINGS

Component of the Model	Required Sensing
Wheat Areas	Direct Satellite Sensings
Soil Moisture	1 Satellite Sensings A. Topography B Evapotranspiration of Plant C Precipitation D Soil Temperature 2 Ground Data Observations A Soil Type B Meterological precipitation measurements
Air Temperature	Direct Satellite Sensing
Stage of Wheat Growth	1 Direct Satellite Sensing 2 Inferences From Satellite Sensing A Temperature B Moisture C. Topography 3. Ground Data Observation A Type of Soil B Planting Dates C Variety and Type of Wheat
Probable Environmental Conditions Before Harvest	1 Climatic Projections 2. Weather Forecasts A Short Range B. Extended
Probable Wheat Yield (Bushels)	Analysis of Interactions of All the Above
Confirmation Correlation and Comparison	

EXHIBIT III-11 WHEAT INVENTORY AND YIELD RELATIONSHIP OF EVENTS FROM SCENARIO TO COMPONENTS OF THE MODEL

Stage in U S	Time	Event From Wheat Inventory Yield Scenario (See Appendix)	Component of Model Which is Affected By This Event
Preplanting	2 June - 31 Aug	Temperatures above normal Soil moisture below normal	Soil moisture Air temperature
Planting	1 Sep - 1 Dec	Soil moisture below average Air temperature average	Soil moisture Air temperature
Planting	1 Sep - 15 Sep	Early plowing of fields to increase infiltration capacity of fields	Soil moisture
Planting	15 Sep - 7 Oct.	Farmers in marginal areas of Montana and the Dakotas fallowed acreage	Soil moisture Wheat areas
Planting	1 Sep - 30 Sep	Soil moisture below normal accounted for the delayed planting of the wheat seed	Soil moisture
Growing season	1 Oct - 3 Nov	Grazing held to minimum to avoid damaging the less developed plants	Wheat areas
Growing season	1 Dec - 30 Dec	Above normal temperatures delayed the penetration of frost into soil	Air temperature
Dormant season	1 Dec - 21 Jan.	Soil moisture continued below normal due to no snowfall	Soil moisture
Dormant season	1 Jan - 21 Jan	Very low temperatures harmful to plants without adequate snow cover occur over large areas	Air temperature

EXHIBIT III-11 (Continued)

Stage in U S	Time	Event From Wheat Inventory Yield Scenario (See Appendix)	Component of Model Which is Affected By This Event
Dormant season	1 Jan - 21 Jan	Strong Canadian winds had a drying effect which is harmful to wheat plants	Probable environmental conditions before harvest
Dormant season	22 Jan - 31 Jan.	Heavy snowfall provided partial replenishment of soil moisture and protection of plants in area east of Rockier	Soil moisture Air temperature
Growing season (winter wheat)	1 Feb - 31 Mar	Above normal temperatures caused heaving (alternate freezing and thawing) Low Soil moisture	Air temperature Soil moisture
Planting season (spring wheat)	1 Mar - 21 Mar.	Wheat fields replowed Loss of 1 2 million acres in Texas, Oklahoma, Kansas and Nebraska due to winter damage Area to be planted in summer crops	Wheat areas Soil moisture Air temperature Stage of wheat growth
Planting season (spring wheat)	1 Mar - 1 Apr	Harrowing for spring wheat on a schedule	Soil moisture Air temperature
Growing season (winter wheat)	1 Mar - 31 May	The growth of winter wheat is behind schedule	Soil moisture Air temperature

EXHIBIT III-11 (Continued)

Stage in U S	Time	Event From Wheat Inventory Yield Scenario (See Appendix)	Component of Model Which is Affected By This Event
Growing season (spring wheat)	1 Apr - 23 May	High temperatures, little precipitation and low soil moisture accounted for wheat at the tillering stages that had less vitality and appeared more stunted than usual	Air temperature Soil moisture Stage of wheat growth Probable environmental conditions before harvest
Growing season (winter wheat)	30 Apr - 24 May	Soil moisture and high temperatures resulted in an additional loss of 2 3 million acres of winter wheat in Texas, Oklahoma, Kansas, and Nebraska	Air temperature Soil moisture Wheat areas
Preplanting	June 1	Allocation of U S. wheat acreage by U S Department of Agriculture	
Growing season (spring wheat)	15 June - 1 July	Above normal temperatures, little precipitation and below normal soil moisture caused wheat to be stunted at boot and heading stages Fertilizer not applied due to low soil moisture content - application of fertilizer would have had an adverse effect	Confirmation, correlation, and comparison

EXHIBIT III-11 (Continued)

Stage in U S	Time	Event From Wheat Inventory Yield Scenario (See Appendix)	Component of Model Which if Affected By This Event
Growing season (winter wheat)	1 June - 30 June	Above normal temperatures, little precipitation, and below normal soil moisture caused wheat to "head" late in Texas and Oklahoma, harvesting was a week later than usual	Confirmation, correlation, and comparison
Harvest (winter wheat)	1 June - 30 June	Wheat at harvest was usually stunted and showed less vitality than usual	Confirmation, correlation, and comparison
Growing season (spring wheat)	1 July - 7 Aug	Above normal temperatures, little precipitation and low soil moisture showed a definite weakening effect from earlier growth stages which had been stunted, kernels were small and lightweight	Confirmation, correlation, and comparison
Harvesting (spring wheat)	8 Aug - 31 Aug	Harvesting on schedule, however, it was confirmed that one million acres of spring wheat were lost in South Dakota, North Dakota, and Montana	Confirmation, correlation, and comparison

EXHIBIT III-12 WHEAT INVENTORY AND YIELD ANALYSIS FOR THE UNITED STATES - TIMING AND NUMBER OF SENSINGS FOR EACH EVENT OCCURRING

Dates	Events	Components: Wheat Areas	Soil Moisture	Air Temperature	Stage of Wheat Growth	Probable Environmental Conditions Before Harvest
		Number of Sensings or Observations				
25 May - 31 Aug	Low soil moisture and high temperatures		97	97		
8 Aug - 31 Aug	Spring wheat harvested	7				
1 Sep - 31 Dec	Soil moisture below average					
1 Sep - 15 Sep	Early plowing of fields					
15 Sep - 7 Oct	Fallowed acreage in Montana and Dakotas	7	123	92		
1 Sep - 30 Sep.	Low soil moisture delayed planting					
1 Oct - 30 Nov	Grazing held to minimum	7				
1 Dec - 31 Dec	Above normal temperatures delayed frost penetration			31		
1 Dec - 21 Jan	No snowfall - below normal soil moisture		21			
1 Jan - 21 Jan.	Very low temperature - no snow cover			21		
1 Jan - 21 Jan	Strong Canadian winds					
22 Jan - 31 Jan.	Heavy snowfall					
1 Feb - 31 Mar	Low soil moisture					
	Above normal temperatures causing heaving					

EXHIBIT III-12 (Continued)

Dates	Events	Components: Wheat Areas	Soil Moisture	Air Temperature	Stage of Wheat Growth	Probable Environmental Conditions Before Harvest
		Number of Sensings or Observations				
1 Mar - 21 Mar	Wheat fields replowed	7			7	
1 Mar - 1 Apr	Harrowing spring wheat on schedule		124	124		
1 Mar - 31 May	Growth of winter wheat behind schedule				21	
1 Apr - 23 May	Spring wheat at tellering stages had less vitality and appeared stunted					30
30 Apr - 24 May	Winter wheat to be harvested accounted for loss of 2 3 million acres in Texas, Oklahoma, Kansas, and Nebraska	8				
June 1	Allocation of U.S wheat acreage by U S D.A					
	Cumulative number of sensings	36	365	365	28	51

Notes (1) Based on analysis of the interactions of the components of the model

Exhibit III-13 is a summarization of the components, dates, and number of cumulative sensings in the water management case The repeated observations give increased confidence to the forecast derived from the satellite-assisted information system The other elements of improved forecasting described in the water management system are available in the wheat inventory yield case, i e , pattern recognition, reduced resolution error, etc

EXHIBIT III-13 SEQUENTIAL DEVELOPMENT OF COMPONENTS OF THE MODEL AND SYSTEM PREDICTIONS

Component of Model	Date Component is Established	Number of Sensings (Allowing for Obscurity Degradation)
Wheat areas	Aug 31 Oct 7 Nov 30 March 21 May 24	7 7 7 7 8
Soil moisture	May 24	365
Air temperature	May 24	365
Stage of wheat growth	March 21 May 24	7 21
Probable environmental conditions before harvest	Jan 1 May 24	21 30
Probable wheat yield (bushels)	May 25	(3)
Configuration Correlation	June 2 & After	
Comparison		

2 Benefits

a Stabilizing Commodity Credit Corporation Wheat Operations

The targets of the U S Department of Agriculture Commodity Credit Corporation (CCC) are to provide an annual supply of wheat sufficient for domestic and foreign demand and maintain an adequate carryover for pipeline stocks and for production variations The CCC serves as the buffer, absorbing excess production and maintaining the adequate carryover in case of deficient output

CCC stocks during the 1958 to 1968 period ranged from 100 million to 1,330 million bushels However, the optimum carryover has been estimated to be 400 million bushels [1] These stocks are needed to take care of reduced production that would result from one very low yield followed by one moderately low yield year

Under the current information system, there is a 2-year lag in the adjustment process to an undesirable carryover level Acreage allotments established in the summer of year (X) affect production in year (X + 1) and carryover levels July 1 (X + 2)

At the time allotment decisions are made, although U S supplies and consumption are known, there is presently little accurate information on foreign crop conditions and potential foreign requirements for U S wheat With this weak link in the supply-distribution balance (exports account for more than half of total disappearance[2]), the carryover July 1 (X + 1) cannot be determined accurately and the error carries forward into the following year

A satellite information system improves the decisionmaking process and reduces the level of CCC stocks by (1) providing better historical information at the time allotments are made and (2) providing better current information that allows midseason adjustments to be made

[1] Bureau of Agricultural Economics, U S Department of Agriculture, Reserve Levels for Storable Farm Products Senate Committee on Agriculture and Forestry, 82nd Congress, 2nd decision, Senate Document No 130 8 1952

[2] Disappearance is a common USDA term which covers wheat used for export, domestic consumption, livestock feeding, seed, and losses due to damage, transport, etc

The net effect is that fewer stocks have to be held to allow for errors in estimation and weather uncertainty

(1) Adjustments Based on Historical Information

At the time final allotment decisions are made (September) the actual world production of the current year's (X) crop in final harvesting is not known, nor is there completely accurate knowledge of the final harvest for the prior year (X - 1) The amount of error involved is illustrated in Exhibit III-6 Using those data, the amount of error that can be reduced by introducing the satellite-assisted system is computed as follows

Year	Current System Error	Satellite System Error	Difference
X	13 percent	2 percent	11 percent
X - 1	4 percent	2 percent	2 percent
Total	14 percent	3 percent	11 percent

The total errors of 14 percent for the current information system and 3 percent for the satellite-assisted information were computed by the following statistical formula for summing errors

$$\text{error} = \sqrt{X^2 + X^2_{-1}}$$

The difference between errors under the current information system and the errors under a satellite-assisted information system is 11 percent Thus, if the allotments are made with a 11 percent reduction in projection error, the acreage and subsequent production will be close to actual needs and will eliminate the need for some CCC stocks From the USDA currently recommended optimum CCC stock levels (not including pipeline) of 400 million bushels, the 11 percent improvement in estimation would allow stocks to be reduced by 44 million bushels to a level of 356 million bushels

(2) Adjustments Based on Current Information

The satellite information system allows constant monitoring of the winter wheat crop This makes possible a fairly

continuous adjustment in production, particularly in adjusting the size of the spring wheat crop to offset winter wheat losses This procedure was explained in the user decision model (section III C 1) The potential adjustment of spring wheat farmers for increasing production in the U S would average 217 million bushels This adjustment in effect becomes a substitute for CCC stocks held as a reserve against weather losses

This adjustment makes it possible to further reduce the optimum level of CCC stocks by 61 percent from the 356 million bushel level to a new optimum of 139 million bushels

(3) Benefit Calculations

The stock levels in the 1971-1990 period are likely to be pushed to a conservative level of 400 million bushels to be capable of absorbing all observed fluctuations [1] With this likelihood, the benefits from the satellite information system make possible reduction in holdings from about 700 million bushels to 561 million bushels (the necessary level for absorbing anticipated uncorrected fluctuations) or a total reduction of 561 million bushels

The monetary benefits result from the savings on operating costs (handling, storage, and transportation) and opportunity cost on invested capital for the number of bushels of stocks that can be eliminated by the satellite system The breakdown of costs based on a possible reduction of 569 million bushels is as follows [2]

Breakdown	$ Millions
Operating cost for storing 261 million bushels at 21 4 cents	55 9
Opportunity cost at 7.5 percent (261 million bushels at $1.52 = $396 72 million capital investment)	29.8
Total potential benefit	85 7

[1] For a detailed explanation of the estimate of future stocks at the 400-million-bushel level, see the section "Noninformation Alternatives," page III-52 in this report

[2] Storage costs and capital investment costs are averages based on 16-year records of actual CCC operations

The potential annual saving would be $85 7 million, with a total savings over a 20-year period of $740 million (discounted 7-1/2%), $616 million (discounted 10%), or $525 million (discounted 12-1/2%) The likely annual rates based on satellite capability and user participation are detailed in Appendix Exhibit H-8

b. United States Producer Benefits

United States farmers will also derive economic benefits from increases in the quality and timeliness of information on United States and world wheat production These benefits accrue from (1) a reduction in the fluctuation in acres used for producing wheat which will reduce the average unit costs of producing wheat (referred to as Production Costs), and (2) the exercise of managerial options on the remaining wheat acres based on new information available to farmers (referred to as Producer Options)

(1) Production Costs

Most producers attempt to operate their farms at their most efficient or optimum point, the point where the average unit costs of production are lowest Year-to-year changes in wheat allotments can cause the unit costs of producing wheat to vary around the optimum point This variation in average unit cost results from the changes in combinations of labor and capital inputs in relation to land

The new satellite-assisted information system will make it possible to reduce errors in information and thus reduce fluctuations in acres around the optimum point of production

The benefits will accrue to farmers by lowering the average unit costs of production by eliminating the "marginal" wheat lands from production Resources that would be invested in wheat can be diverted to other uses

Historically, the national wheat acreage allotments in the period 1954-1967 ranged from 47 8 to 68 2 million acres This variation resulted in a wide range of unit costs of production for wheat farmers These effects are illustrated by the unit cost curve in Exhibit III-14 The unit cost curve shown was derived for wheat-fallow enterprises in the Northern Plains and is thought to be indicative of the cost relationships of the other

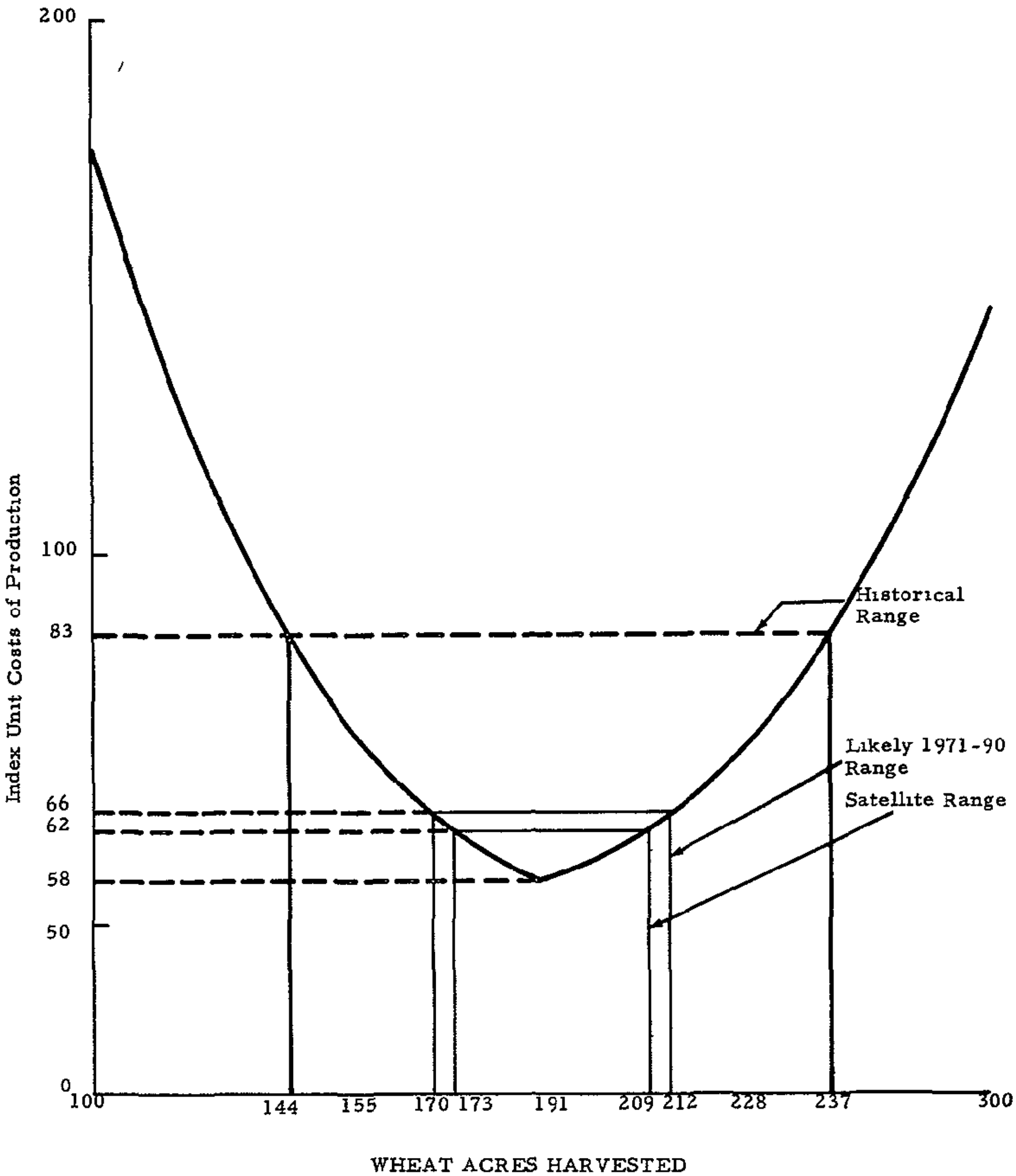


EXHIBIT III-14 UNIT COST CURVE FOR WHEAT-FALLOW ENTERPRISE IN THE NORTHERN PLAINS, UNITED STATES

wheat areas The range in average number of wheat acres harvested per farm for this type of farm was from 144 to 237 acres during the 1954-1967 time period The index of unit costs for average yields of 20 bushels per acre ranged from a high of about 83 at 144 acres to a low of 58 at 191 acres and increased again to a high of about 83 at 237 acres The average index of unit costs was 70 5 That range of acres produced large stocks of wheat which averaged about 900 million bushels in a year, but peaked at about 1,300 million bushels

Without the satellite-assisted system, stocks during the 1971-1990 period may average about 400 million bushels [1] The range (range = 42 acres) of acres that would give that level of production would be from 170 to 212 acres. The unit cost curve would yield an index of 66 at the high point and a low of 58, with the average at about 62

The satellite-assisted information system would reduce the range of acres in production by eliminating errors in estimation and hence the acreage that would be required to achieve optimum production levels The satellite system has the capability of reducing estimation errors by ± 13 percent over current systems assuming a normal distribution This could conceivably reduce the range of acres below the likely 1971-1990 level by 13 percent. The range of acres needed could run from a low of 173 acres to a high of 209 acres The index of unit costs under this situation would be from 62 at 173 acres, to the low of 58 at 191 acres, and return to a high of about 62 at 209 acres The index of unit costs would average about 60 for the satellite information system. The cost enterprise relationships are discussed in greater detail in Appendix H.VI.

The monetary benefits accrue from reducing the average unit costs of producing wheat PRC estimates of production expenses per acre result in an average annual expenditure of $1,446 million for producing wheat under the likely 1971-1990 nonsatellite system With the satellite assisted information system making possible a reduction of 13 percent below the likely 1971-1990 level, the potential saving of resources would

[1]For a detailed explanation of the estimate of future stocks at the 400-million-bushel level, see Subsection III.C.5, Noninformation Alternatives.

approximate $29 million per year The discounted savings over a 20-year period are summarized in Exhibit III-15 and shown in detail in Appendix Exhibit H-13

With the adoption of the satellite-assisted information system by other free-world, developed, wheat-producing countries, there is the distinct possibility that they may experience similar economies in the production of wheat

While there is inadequate information to develop unit cost curves for other countries, the assumption was made that the other free-world, developed countries experience cost curve relationships similar, if not identical, to those of the United States No attempt to include the bloc countries was made because reliable production and cost data are difficult to obtain. Developing countries were excluded because they are dealt with separately in another section The other free-world, developed countries likely to benefit are wheat exporters whose acreage may be influenced by world markets The acres of wheat in these countries in proportion to United States acres form a basis for a comparison The ratio of such acres in selected countries to United States acres is 1 6, therefore, a simple extrapolation was made on that basis These benefits are summarized in Exhibit III-15 below and explained in greater detail in Appendix H VI

EXHIBIT III-15 BENEFITS FROM REDUCING UNIT COSTS OF PRODUCING WHEAT, UNITED STATES AND OTHER FREE-WORLD, DEVELOPED, WHEAT-PRODUCING COUNTRIES ($ Millions)

Benefits to	20-Years Discounted at		
	7.5%	10%	12 5%
United States	$273	$225	$192
Other Free-World, Developed Wheat-Exporting Countries	400	334	286
Total	$673	$559	$478

(2) <u>Producer Options</u>

The second form of benefits accruing to farmers is derived from the use of satellite information to improve their managerial decisions Wheat farmers in the United States have several production options available to them at several points during the crop cycle The options are summarized in Exhibit III-16 With improved information, the farmers will be better able to make investment decisions which will either maximize production or minimize losses on the current wheat crop

It is not reasonable to expect each of these options to be influenced by the system every season, however, farmers will be able to benefit from the availability and timing of data not currently available to all, or not to the same degree, as would be provided by the satellite system

The satellite system would allow the farmer to alter production practices in accordance with the conditions as they occur Potential dollar benefits that would accrue to the U S wheat production from these options were calculated for three major areas changing the crop cycle, cattle grazing, and the rate and amount of intermediate fertilizer based on better and more timely satellite information

The winter wheat crop cycle could be changed, saving fall production costs, in those years where the farmer was told that he would have a bad fall but a satisfactory spring growing period In the 20-year period under study it was estimated that this condition would occur three times for a potential saving of $1, 811 million in fall planting costs

The benefits from improved information on when to increase or decrease grazing of winter wheat, would be about $113 million maximum over 20 years Benefits from knowing when and how much intermediate fertilizer to apply would be a potential $290 million in 20 years

These maximum/potential rates were modified by the ability of the satellite-assisted system to provide data and the rate at which farmers are likely to adopt the new technology This is discussed in Appendix H VII

The assumption also was made that the rest of the free, developed winter wheat producers possess the capability to exercise options in

EXHIBIT III-16 OPTIONS AVAILABLE TO FARMER FOR CHANGING PRODUCTION FUNCTION[1]

	Stage of Production Cycle			
	Planning/Preparation	Planting	Intermediate	Harvest
Options Available	Plant/Fallow	Change fertilizer	Fertilizer	Delay harvest
	Plowing technique	Change seed amount and type (variety)	All-purpose fungicide herbicide	Plow after harvest
	Custom-hired work	Change labor	Revise crop cycle (winter wheat)	Storage facilities
	Cattle grazing	Change crop	Cattle grazing	Custom-hired work
		Custom-hired work		Cattle grazing
		Cattle grazing		

[1] Limits to options Operating capital availability
Investment capital
Labor inputs. Farm originating or custom-hired
Material inputs certified seed, fertilizer
Meteorological condition

production shifts by using satellite information The extrapolation of U S. benefits to the rest of the developed world was made on the ratio of other free-world, developed, winter wheat producing countries' acres to United States winter wheat acres, a ratio of 1 9 to 1 On that basis, the benefits would be of the magnitudes expressed in Exhibit III-17 The detailed calculations are explained in Appendix H VII

EXHIBIT III-17 BENEFITS FROM EXERCISING PRODUCER OPTIONS, UNITED STATES AND FREE, DEVELOPED WHEAT-PRODUCING COUNTRIES ($ Millions)

	20-years Discounted at		
Benefits to	7-1/2%	10%	12-1/2%
United States	$ 592	$ 482	$ 396
Other Free-World, Developed Countries	1,044	845	694
Total	$1,636	$1,327	$1,090

c. Benefits to Less Developed Countries and the United States Foreign Economic Assistance Program

The satellite-assisted information system will greatly aid the less developed countries in their efforts to maximize agricultural production by providing more reliable information for improved national planning. The direct monetary benefits from this assistance take two forms (1) a faster rate of agricultural and economic growth for the less developed countries (LDC's) and (2) more efficient returns on U S economic assistance investments

The benefits result from preventing declines in food grain production trends when current satellite information on crop conditions is available in time to take remedial or offsetting action

In the LDC's located in the tropical or subtropical zone which allows almost continuous cropping, the national government of these countries has the opportunity to make adjustments potentially in the first and certainly in the second crop Satellite information, for example, on the yield of the first crop before harvest (currently impossible in most LDC's) will permit adjustments to be made in the second crop to offset declines in the first crop. The national planning framework of the centrally

planned agrarian sectors makes possible more accurate national direction and assistance to ensure farmer response in proper allocation of land resources, adjustment to weather factors, fertilizer applications, and other field and harvesting operations In addition, special attention can be directed toward shifting land and labor resources in a way that will aid in moving from a subsistence to a commerical agricultural economy

With the satellite information system, the capability exists to adjust resources going into food grain production Resources existing within the agricultural sector can be redirected in more efficient ways and, consequently, result in a higher growth rate for the agriculture sector and eventually for the entire economy of the LDC's It can reasonably be assumed that a good portion of this adjustment is made possible through the interjection of new capital in the form of P L 480 and other economic assistance from the United States

In the LDC's, the average annual fluctuations in wheat production are somewhat less than developed country fluctuations, i e , about 7 percent The satellite information system has the capability to measure all but about 2 percent of the fluctuation at harvest time This makes it possible to mobilize national plans for dealing with about 5 percent of the fluctuation This 5-percent adjustment must further be modified by the rate at which farmers comply with government programs to adjust production plans both between cropping seasons and during early portions of the growing season The ultimate rate of farmer compliance was estimated at 90 percent for this study This means that instead of being able to adjust the full 5 percent of the fluctuation, adjustment to 4 5 percent would be a more reasonable assumption In other terms, we are able to adjust, at most, 4 5 percent (or 65 percent) of the total 7-percent average fluctuation in annual wheat production

Food grain production in the wheat exporting LDC's is a major part of total agricultural production, and trends in production for all of the agriculture sector are known to be much the same The benefits calculated from stabilizing food grain output are subsumed to total agricultural production The net result is a higher growth rate for the agricultural sector

and, subsequently, a higher growth rate for the entire economy of the LDC's where the agricultural sector is frequently about 40 percent of the total economy

In a group of 14 LDC's in South America, Africa, the Near East, and the Far East (the principal wheat-food grain producers on each continent), offsetting 65 percent of the declines in agricultural production would result in a 2 6 percent improvement in the growth rate of the agricultural sector In monetary terms, this would increase the value of agricultural production a potential $940 million a year (in constant 1957-1959 dollars) The benefits are summarized in Exhibit III-18

The benefit to the United States from an improvement in agricultural production in the less developed countries is in the form of greater return on U S economic assistance investment. During the 1958-1967 period, U S economic assistance averaged about $3,485 million per year -- $1,367 million for P.L 480 grain shipments and $2,118 million economic assistance A 2.6 percent improvement in performance of the agricultural sector of LDC's would be the equivalent of 1.0 percent in the total economy, since the agricultural sector makes up 40 percent of the total economy in most such countries.

Thus the direct benefit in the form of increased returns to the total U S assistance would have averaged a maximum of 1% of investments or about $35 million per year

The annual benefits were scaled according to the capability of the satellite system and user participation rates These and other detailed calculations are shown in Appendix H VIII.

EXHIBIT III-18 BENEFITS TO THE UNITED STATES AND LESS DEVELOPED COUNTRIES THROUGH IMPROVED GDP ($ Millions)

Benefits to	20-Year Discounted at 7-1/2%	10%	12-1/2%
Increased Return on U S Aid	$ 214	$ 175	$ 148
Increase in LDC Gross Domestic Product	5,593	4,607	3,864
Total	$ 5,807	$ 4,782	$ 4,012

d Benefits in the Agribusiness Sector

Industries selling goods to farmers and industries buying farm produced goods will benefit from the satellite information system by using the information on projected wheat production to better gauge their own production and management decisions

The principal industries for which benefits were calculated were farm machinery manufacturing, fertilizer manufacturing, and chemical pesticides manufacturing Benefits in each of these industries were in the form of resources saved on storage costs and the interest rate on inventory in storage With advance information, these industries will be able to adjust manufacturing in years of declining wheat production Over a 20-year period, the undiscounted estimated savings to the industries would be farm machinery manufacturing, $886,000, fertilizer manufacturing, $2,300,000, and chemical pesticides manufacturing, $700,000 These savings would be much larger if expanded to cover all grains because none of these agribusiness products are unique to wheat, but all suffer inventory problems due to fluctuations in total agricultural production

Benefits were not calculated for the commercial grain elevators, millers and processors Principal variations in wheat production are handled by the Commodity Credit Corporation which acts as a buffer in times of overproduction and underproduction Therefore, the major burden of stress does not fall on the commercial sector Benefits were not calculated for the grain transportation sector because of the difficulty in defining a problem and quantifying benefits The principal problem faced by the transportation industry, particularly railroads, is the shortage of boxcars at harvest time When the railroads have perfected an interline computerized scheduling system, they could profitably use the satellite information system to help route boxcars based on regional production projections

The annual and 20-year benefits to the United States agribusiness sector are summarized in Exhibit III-19 The details are discussed in Appendix H IX

EXHIBIT III-19 BENEFITS TO THE U S AGRI-BUSINESS SECTOR ($ Millions)

	Annual	20-Year Discounted at 7-1/2%	10%	12-1/2%
Total Agribusiness Benefits	0 16	1 8	1 5	1 3

The total benefits due to changes in wheat production management resulting from introduction of the satellite-assisted information system in the United States and other countries are summarized in Exhibit III-20 The 20-year benefits have been discounted 7-1/2 percent, 10 percent, and 12-1/2 percent

Benefits	United States 20-Year Discounted			World (excluding U S) 20-Year Discounted		
	7-1/2%	10%	12-1/2%	7-1/2%	10%	12-1/2%
Reduce CCC Stocks	$ 740	$ 616	$ 525	---	---	---
Reduce Unit Costs of Producing Wheat	273	225	192	400	334	286
Producer Options	592	482	396	1,044	845	694
Improved GDP in LDC's	214	175	148	5,593	4,607	3,864
Agribusiness Benefits	2	1	1	---	---	---
Total	$1,821	$1,499	$1,262	$7,037	$5,786	$4,844

EXHIBIT III-20 - TOTAL BENEFITS - WHEAT PRODUCTION MANAGEMENT ($ MILLIONS)

3 Total Costs

The water management system configuration, because of the timing and orbiting conditions, will meet the requirements of the wheat production management case The costs are therefore the same as described in the water management case

(S) It is probable that the wheat production management case could be viable in the U.S and possibly overseas without the use of radar in the satellite The costs of such a system are discussed in Appendix D However, since it is likely that the wheat production management case will be a part of the same satellite configuration as the water management case, the radar can be used to improve reliability of sensings, particularly in other parts of the world where ground weather stations and adequate ground truth are lacking

4 Sensitivity

In the simplest terms, the system operational procedure is a continuous process through three basic sequential activities (1) observing, (2) evaluating, and (3) forecasting The system product is the forecast that is derived from information based on data gathered by satellite The observational aspects of the system are detection and recognition of current conditions, while the evaluation aspects are associated with interpretation and comparison of these conditions with historical or nominal values Forecasting extrapolates the result into the future

The significance here is that the ability to predict depends not only on the ability to see today but also on the ability to perform two determinations (1) how today differs from the past, and (2) how this difference affects tomorrow For example, the yield of winter wheat at harvest is affected by, among other things, the precipitation received earlier in the various growth stages Therefore, the accuracy of a yield forecast made in November for the subsequent June harvest depends not only on the accuracy of observing cumulative precipitation or soil moistures since planting, but also on the accuracy of two determinations

- How the cumulative precipitation in the area this year compares with historical values for this date

How the historical value of bushels per acre will be altered by this variance

Analysis associated with this study has identified the primary seasonal factors that influence the condition and quantity of the eventual harvest These factors are discussed in context with the example scenario for the Wheat Production Analysis System and their relationship to seasonal events that occurred between planting and harvest These influencing factors are discussed further in the section on the user sensor model in terms of specific satellite observational parameters, along with the requirements for frequency of observation and sensor resolution The analysis shows, in summary, that no major difficulties are anticipated in the ability to accurately detect and measure those parameters which predominately influence yield and inventory

It is important, however, to examine the potential forecast accuracy in reference to requirements for developing the correlation of these observed parameters to yield and inventory in terms of quantified rather than qualified relationships The point here is that, not only is there a need for further research in agricultural sciences, but also, this research will lead to greater marginal improvements in system effectiveness than would additional research leading to improved sensors

A contributing reason for the lack of more comprehensive research in the past on the effects of, for example, time-phased soil moisture on yield at harvest is that there would be no practical means for applying the result of this research on a broad, national scale The reason for this is simply the lack of an effective data-gathering system that can provide continuous, timely values of soil moisture levels, measured in acres rather than counties or states, for all localized wheat-producing areas

Because a satellite-supported system can provide this exhaustive, timely data easily processed by computers, the need for, and contribution of, further agricultural research on correlation effects has become increasingly significant. This does not mean, however, that the needed agricultural research is a prerequisite for the justification of feasibility of the proposed satellite-supported system or that the system

implementation is contingent upon the availability of these correlative relationships What it does mean is that the system performance effectiveness and cost/benefit ratios will experience incremental increases as analytical correlation relationships derived from research replace those empirical relationships derived from trend analysis of observed behavior

In conclusion, the system does not appear to require sensor capabilities above those apparently within the state-of-the-art when proved out by development R&D satellite attitudes Costs would be quite sensitive to attempts to push basic research to obtain improved sensors (i.e , an Advanced II capability) and quite insensitive to attempts to use less than Advanced I sensors to economize on weight, power, etc On the other hand, pioneer work on yield models and other so-called earth science components of the integrated model must be realized in main if projected benefits are to be realized

5 Noninformation Alternatives

a General

This subsection of the report compares, on a cost-benefit basis, the satellite information system discussed in Section II and employed as a source for data on worldwide wheat inventory yields with the noninformation alternative However, for a satellite system to be absolutely preferred, it must be superior to other, noninformation alternative solutions to the set of problems solved by the satellite--solutions that might be employed during the 20-year time period under consideration

The only noninformation alternative to better information on worldwide yields seems to be that alternative which has been the policy of the U S for the last 30 years This policy calls for considerable wheat storage resulting from both a high minimum desirable annual carryover reserve of wheat--from 400 to 700 million bushels--and recurring overproduction that results in both the procurement and

storage of excess stocks The next subsection of this report will consider the amount and costs of wheat storage according to the current U S policy

b Cost of the Noninformation Alternative to Wheat Yield Information

The goal of the U S wheat production and storage programs is to provide a supply of wheat each year sufficient to provide for domestic and foreign demand and to maintain a minimum adequate carryover for pipeline (commercial) stocks and for yield variations due to weather While there is no official determination of an adequate minimum carryover level, a comprehensive study of desirable stock levels was prepared by the Bureau of Agricultural Economics for the Senate Committee on Agriculture and Forestry [1] This report recommended a desirable carryover of about 500 million bushels--approximately 100 million bushels for working or pipeline stocks and 400 million bushels in storage to remedy reduced yields that would result from one very low yield year followed by one moderately low yield year (This would have taken care of all contingencies since 1900, except for the drought years 1933-1936) With the increased level of wheat exports in recent years, however, pipeline stocks now require about 150 million bushels rather than 100 million, so that total carryover stocks today should approximate 550 million bushels Domestic consumption of wheat has remained quite level.

Historical experience in stored inventories of U S wheat from 1953 to 1968 shows a range of about 100 to 1,300 million bushels. It is quite unlikely, however, that the current program would allow stocks to get to the high extreme of that range in the future The program has been modified to give more flexibility on downward acreage adjustments

[1] U S Congress, Senate, Reserve Levels for Storable Farm Products, Senate Document No 130, 82nd Congress, 2d Sess., 1952, p 5

In the past, bad situations were allowed to get successively worse, but under the current information system, there is only a 2-year lag in the adjustment process to an undesirable carryover level Acreage allotments established in the summer of year X affect production in year X + 1 and carryover levels of July 1 of year X + 2. At the time of allotment decision, although U S supplies and consumption are known, there is little accurate information of foreign crop conditions and potential foreign requirements for U S wheat With this weak link in the supply-distribution balance (exports account for more than half of total disappearance), the carryover of July 1 of year X + 1 cannot be determined accurately, and the error carries forward into the following year The successive buildup in inventories by a surplus 300 million bushels in 1954 and by an additional 200 million bushels in 1955 is a case in point Similarly in the process of reducing stocks from 1965 to 1967, the 2-year inflexibility lowered the level of stocks to about 250 million bushels below desirable levels Thus, with a 2-year lag, and 2 successive years of bad or good weather and other variables, the range in stock levels could be from 0 to 900 million bushels, with around 400 million bushels as the desirable stock level but a constant bias toward stocks in excess of those desired This bias is due to the constantly improving yields in wheat, as well as a constant conservative attitude--better to store some extra wheat than to run the risk of famine For purposes of this analysis, an average stored inventory, exclusive of pipeline supplies, of 400 million bushels will be assumed for the next 20 years. This amount is less than the actual inventories experienced in 11 of the last 15 years

The total annual cost of the current wheat storage program is composed of two major components annual operating costs and opportunity costs During FY 1968, the average cost for storage and handling of a bushel of wheat in the government reserves was 12 6 cents, the average cost for transporting that bushel was 8 8 cents, and the average investment cost of that bushel of wheat was $1 52 Thus, assuming constant FY 1968 rates, the annual operating cost of a 400-million-bushel storage program is ($0.126 + $0 088) x 400, 000, 000, or $85 6 million. If

an opportunity cost rate of 7.5 percent is used, the opportunity cost of the 400-million-bushel storage program is \$1 52 x 400, 000, 000 x 0 075, or \$45.6 million The sum of the two major elements results in a total annual cost of \$131.2 million in constant FY 1968 dollars for storing 400 million bushels.

5⊕

D Wheat Rust Control

The stress problem reduces agricultural output an estimated $13 billion annually The major stress case involves rust which attacks wheat In fact, there are a family of fungi diseases that attack a number of crops

To determine the applicability of the satellite-assisted information model, the stem wheat rust case was studied in detail It was found to be a very rapidly moving phenomenon which periodically explodes in epidemic proportions It will become apparent that only slightly less frequent coverage is required than that specified in the water management case It was also shown that the satellite constellation designed for the Pacific Northwest will give the 12-hour coverage of the U S wheat areas required for the rust case

The choice of the sensor package selected above will be confirmed by considering the user decision model in this subsection The summarization of the scenario will relate the sensors to the dynamics of a representative rust season

Benefits will then be calculated to the U S stem wheat rust case These benefits will then be extrapolated to other fungi diseases and then extrapolated to the world as a whole Finally, an alternative information and noninformation system will be considered

An overview of the wheat rust case can again be supplied by the system dependency matrix The satellite system offers a number of measurements valuable to an integrated rust monitoring and forecast model Exhibit III-21, the system dependency matrix, illustrates the sensors used, physical measurements and forecasts made, and the management areas/benefits

1 User Decision Model

The variable factors which determine whether a farmer will sustain losses from wheat rust in a given year are weather conditions, mass air movements, the timing and quantity of the original infection, the rust races which are present, and the wheat varieties grown

EXHIBIT III-21 WHEAT RUST CASE - EARLY OPERATIONAL SYSTEM

MANAGEMENT AREAS/BENEFITS

	Crop Identification	Crop Area and Location	Crop Vigor	Stress Identification	Stress Severity	Stress Location	Infection Probabilities	SENSORS: TV	MSS	Radar	MWR	IR Scanner
Increased Yields	3	3	2	2	2	2	2					
MEASUREMENTS												
Minimum Daily Temperature	4	4	3	3	3	3	2	4	1/2 (H)		4 (A H)	1/2 (H)
Maximum Daily Temperature	4	4	3	3	3	3	2					
Rainfall	4	4	2	4	4	2	2	3 (B C I)	2 (B C I)	1/2 (B C I S)	2/3 (A B C I)	2/3 (B C I)
Soil Moisture	4	4	3	3	2	2	2	3 (B C)	2 (B C)	2 (B C)	2/3 (A B C)	2/3 (B C)
Plant Temperature	2	2	2	2	2	2	4	4	1/2 (A F)	4	3/4 (A)	1/2 (A F)
Respiration	3	3	3	2	2	2	2	4	4	4	4	4
Evapotranspiration	3	3	2	2	2	2	2	4	2 (A K)	4	3/4 (A K)	2 (A K)
Acres of Wheat	1	1	4	4	4	4	4	2 (D G)	2 (F G)	2/3 (D E)	3/4 (A)	3 (E)
Wind (direction and velocity)	4	4	4	4	3	2	2	4	4	3/4	3/4	4

Legend
1 Sufficient
2 Major Contribution
3 Contribution
4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT III-21 (Continued)

A Too low a spatial resolution

B Can detect but not quantify

C On the basis of area extent only

D On the basis of low resolution shape information

E Insufficient resolution for identification by shape and insufficient spectral information

F Would be excellent if sufficient spatial resolution were possible

G On the premise of spectral recognition

H High frequency observation required

I After fall of rain

J During fall of rain at time of passage

K Depending on time of diurnal cycle, transpiration controls plant temperature

L Could detect wet versus dry soil

M Could detect heavy rain

N Obscured by clouds

O Limited swath width

P Thermal infrared channel

Q Qualitative indication

R Inference from cloud cover

S Better resolution offers improvement

T Better resolution would improve interpretability or discriminability

U Improved discrimination, technique, accuracy, or interpretability

In the past, the principal method for limiting losses of crop value to rust has been to emphasize the planting of wheat varieties that are genetically resistant to infection from specific races of rust Considerable losses to rust have occurred when relatively rare races of rust have broken out at epidemic levels During these years, chemical sprays are very important as a means of minimizing damage from rust

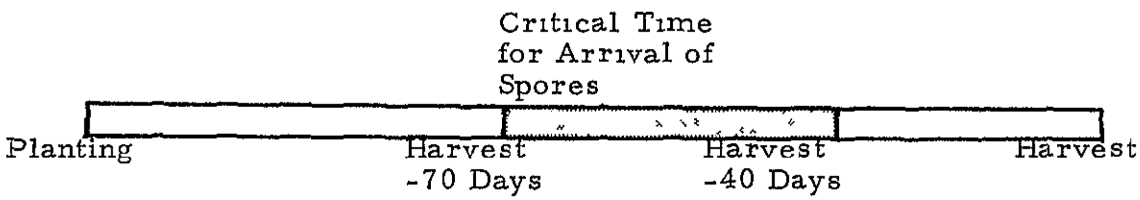
The chemical sprays now available for use are protectant fungicides which kill rust spores (the infectious stage of rust) on contact These sprays control only the pathogen which is outside the plant For this reason they must be sprayed on the plant either before or immediately after the spores fall on the plant Rain is the principal delivery mechanism for spores, and rain washes the protectant fungicides from the plant In most cases, therefore, the spray should be applied immediately after the spores have arrived The spray then arrests the development and reinfection of the rust on the plants until the next heavy rain

In the past, farmers have hesitated to invest in spraying operations because they did not know, until the rust had damaged their wheat, that spores had arrived at a time in the growth cycle of their crop that made damage by harvest time likely

The satellite-supported rust observation, analysis, and control system will emphasize not only the genetic relationships between rust and wheat, but also the other factors that determine damage weather conditions, mass air movements, and the time and amount of the original infection This system will inform the farmer· whether the conditions of his soil and his crop make his wheat subject to heavy rust losses *if* rust spores arrive,[1] whether the arrival of spores is imminent With this information the farmer can prepare the material and manpower needed for spraying operations, and he can perform the spraying at the time that will minimize losses to rust The timing of these decisions is shown in Exhibit III-22

[1]A proposed technique for making this prediction is included in Appendix I. I.

EXHIBIT II-22 USER INFORMATION - DECISION MODEL WHEAT RUST CONTROL



	Information Required	Timing of Information	Decision
1	Damage at harvest will be greater than 25 percent if spores arrive on any day Harvest -70 days to Harvest -40 days	7 days before the arrival of spores from southern area	Prepare manpower, equipment, and material for spraying operations
2	Spores will infect wheat within 24 hours	1 day before arrival of spores	Spray

As depicted in Exhibit III-23, the spread of rust generally follows the warming and cooling of the North American Continent The rust spores that are present on northern wheat at harvest time are blown southward where they infect grasses, some of which may be infected already by rust which survived the summer By late fall, many areas of Texas and Mexico are infected, and in these areas stem rust can survive the winter In the spring, when weather conditions are favorable, the rust spores sweep northward with the advance of the crop season and southerly winds This northward spread is both local and long range, depending on the weather conditions Thus, rust in Texas and Mexico can spread from field to field or ride the wind to Kansas or even farther to the north Infections in Kansas then serve as a source of primary inoculum for fields in the northern states and Canada

Spores are carried from the plants into the air by rising air currents and local turbulence The distance that live spores can travel is a function of the time span of their viability and the speed of the wind at the altitudes that they inhabit For the purposes of this study, the following hypotheses are proposed (1) the spores can live for 48 hours in the air, (2) spores are found as high as 20,000 feet, but significant concentrations of viable spores are found only at 5,000 feet and below Employing these hypotheses, it is then possible to estimate the trajectory of spores away from infected fields Once the source area for the spread of spores is located and measured, and the direction and speed of winds below 5,000 feet are ascertained, meteorologists can draw the 48-hour trajectory of spore-carrying winds If rain is predicted for areas within the trajectory, the fall-out of spores is also predictable By a continually updated analysis of all the factors involved, it is also possible to make lower level predictions of the regional development of rust even before rust spore trajectories can be developed This long-range capability will improve as data on an increasing number of seasons are gathered, and within each season, as an increasing number of observations is made

In general, the rust forecast system will be able to forecast rust damage by sectors of the wheat growing area These sectors

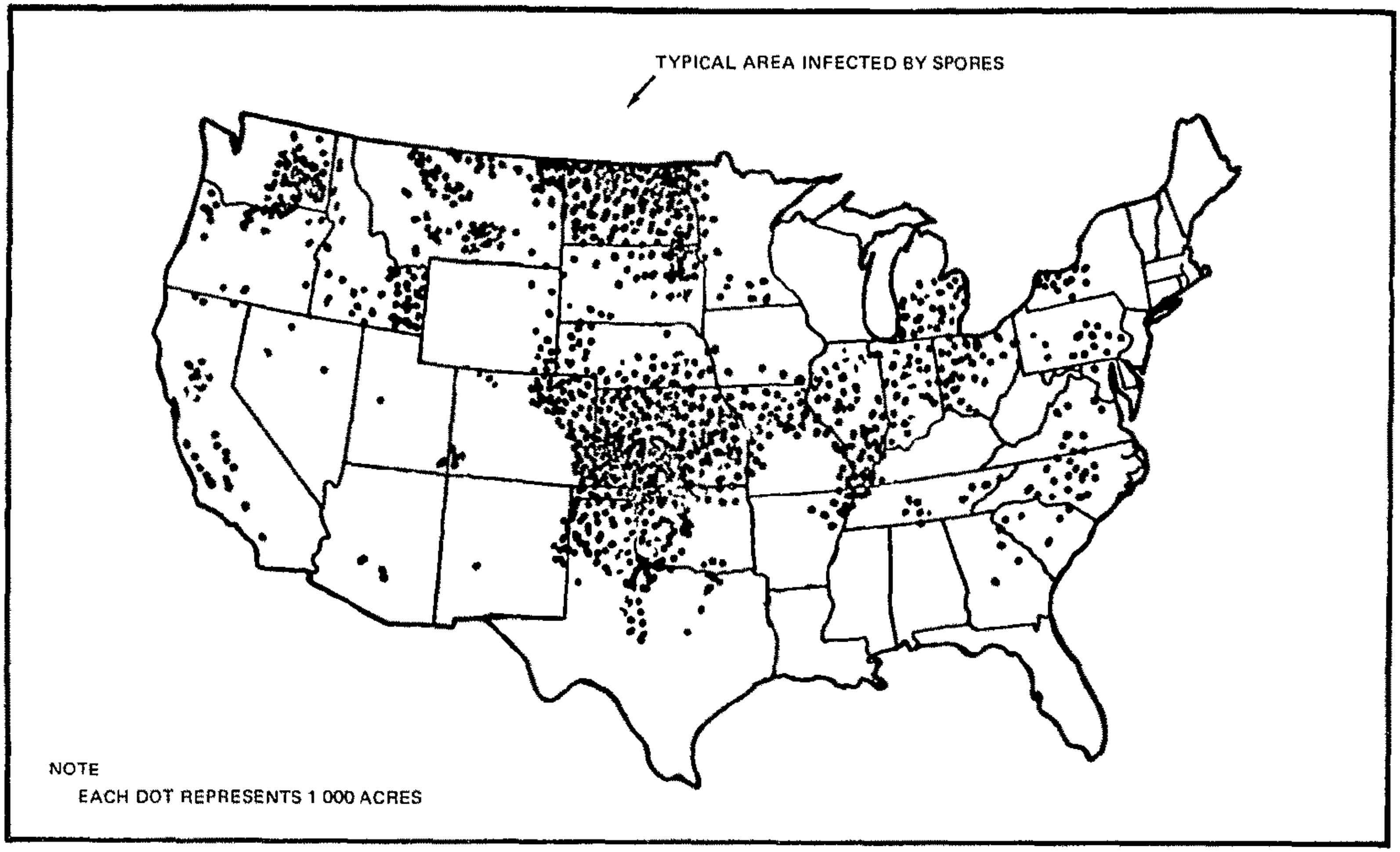


EXHIBIT III-23 WHEAT ACREAGE IN THE UNITED STATES AND SPORE MOVEMENT

represent the approximately 20- to 25-day period between the arrival of spores in one sector and the blow-away of large numbers of spores from that sector northward Exhibit III-24 shows a possible delineation of these sectors The satellite-supported system will monitor, analyze, and update the development of rust in sector 1 For all other areas, the system will observe and analyze those factors that determine the likelihood of heavy damage if spores arrive Once the forecast system can see that spores will enter sector 2 and develop, estimates of the arrival of spores in sectors 3, 4, 5, and 6 can be made These estimates will be updated and improved as the satellite system makes more observations and analyses of sectors 1 and 2

The maximum required number of observations that the satellite must provide of the wheat areas of the United States is two per day During the fall and winter, however, fewer observations will provide all the information that is necessary for the analysis of the growth of wheat and the spread of rust The schedule of sensings in Exhibit III-25 would provide coverage that is sufficiently frequent The number of sensings of each area amount to approximately 180

Since the damage caused by wheat rust is uneven (see Strategy of Control of Rust in Appendix I. II), with heavy losses on the average every 3 years, it is apparent that heavy damage occurs only when certain unique conditions arise, or when a number of unusual conditions coincide. The National Rust Spread Scenario, which is included in Appendix I. III, is a hypothetical case of the development of a series of widespread, unusual conditions favorable to rust. The Rust Observation Analysis and Control Scenario, which includes satellite support, describes the operation of the satellite-supported system on a local and national basis within the national scenario, and it describes some examples of the many variations of the unusual conditions that are possible. It is described in Appendix I. IV.

In general, the coincidence of conditions that is described below includes the following factors

- Heavily infected source areas of rust inoculum early in the growing season, this depends heavily on previous year infections
- A dry period following the development of rust pustules in the source area that causes local convection currents

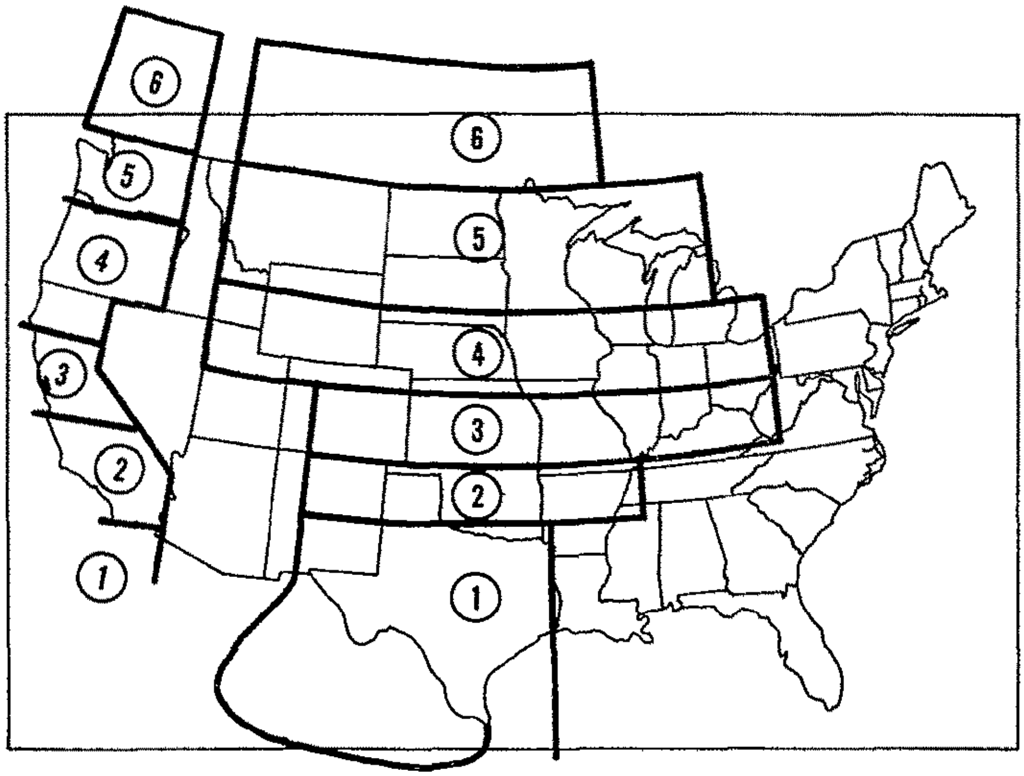


EXHIBIT III-24 SECTORS OF WHEAT RUST OBSERVATION

EXHIBIT III-25 SCHEDULE OF SENSINGS

		Possible Number of Sensings	Number of Sensings Degraded by Obscurity
Sector 1		162	135
June 15	to January 31		1 Obs Per Week
February 1	to March 15		1 Obs Per Day
March 16	to April 15		2 Obs Per Day
April 16	to June 14		1 Obs Per 2 Days
Sector 2		190	158
July 1	to February 15		1 Obs Per Week
February 16	to March 15		1 Obs Per 2 Days
March 16	to May 15		2 Obs Per Day
May 16	to June 30		1 Obs Per 2 Days
Sector 3		167	139
July 16	to February 28		1 Obs Per Week
March 1	to March 30		1 Obs Per 2 Days
April 1	to May 15		2 Obs Per Day
May 16	to July 15		1 Obs Per 2 Days
Sector 4		168	139
August 1	to March 14		1 Obs Per Week
March 15	to April 30		1 Obs Per 2 Days
May 1	to June 15		2 Obs Per Day
June 16	to July 30		1 Obs Per 2 Days
Sector 5		145	120
August 15	to March 31		1 Obs Per Week
April 1	to May 31		1 Obs Per 2 Days
June 1	to June 30		2 Obs Per Day
July 1	to August 14		1 Obs Per 2 Days
Sector 6		175	145
September 1	to April 15		1 Obs Per Week
April 16	to June 15		1 Obs Per 2 Days
June 16	to July 31		2 Obs Per Day
July 16	to August 31		1 Obs Per 2 Days

- Local convection currents to carry the spores into the air
- Southerly winds that carry the spores northward
- Rain within the air masses that are carrying the spores northward, this rain delivers the spores to the surface of wheat plants in previously rust-free areas
- Susceptible wheat that is 40-70 days before harvest in the area in which spores fall
- 60° to 70° F temperatures combined with 4 hours of free moisture during the night to enable the rust spores to germinate following delivery to the susceptible wheat plants (hosts)
- Daytime temperatures 75° to 85° F with free moisture and slow drying of plants for 4 hours to enable germinating spores to penetrate the plant
- Ten to 15 days of temperatures averaging around 70° F with sunny conditions in order for the rust to develop within the plant and to break through the plant surface as pustules, when these pustules appear, the area is now a potential source area for the spread of spores to other wheat plants
- Continuous repetition of dry conditions, spore cloud development, winds, rains, susceptible wheat, warm moist nights, warm days, enabling the rust to produce many generations in a short period, otherwise widespread heavy damage could not result[1]

The repeated sensing by satellite or ground sources of the unusual rust-intensifying phenomena as they develop will enable the rust observation analysis and control system to provide the information required for spraying decisions at the proper time. The observation of these conditions will be continual, and each will contribute to one or more of the components of the model beside the sensings (satellite and ground source) that are required to establish the components of the model. The components of the model represent the characteristics of wheat, soil, rust, and weather that are needed to make predictions upon which the user can make decisions.

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[1] A recapitulation of the environmental requirements for wheat stem is found in Appendix I. V.

EXHIBIT III-26 RUST CONTROL MODEL

Component of Model Each Resolution Element	Required Sensings
Wheat areas	Satellite sensings area
Variety of wheat	A Seed sales B USDA data
Soil moisture	A Satellite sensings 1 soil moisture directly 2 topography 3 precipitation areas B Ground data 1 type of soil 2 meteorological precipitation measurements
Stage of wheat growth	Inferred from correlation of A Satellite sensings 1 temperature 2 moisture 3 topography B Ground data 1 type of soil 2 planting dates 3 variety of wheat
Probable conditions before harvest	Climatic projections Weather forecasts A Short-range weather forecasts B Extended weather forecasts
Probable date of harvest	Analysis of interactions of all factors above
Location, extension, and severity of rust	Satellite sensing A Stress confirmed as rust by ground inspection B Stress within rust pattern

EXHIBIT III-26 (Continued)

Component of Model Each Resolution Element	Required Sensings
Type and race of rust	A By ground inspection until rust pattern is established B By satellite sensing after pattern is established
Probable damage to wheat if specific races of rust arrived on any day 40 to 70 days before harvest	Current virulence and prevalence of races of rust relative to varieties of wheat planted Climate projections Short-range weather forecasts Extended weather forecasts Current location, extension, and intensity of infections by each race of rust
Spore cloud development	Satellite sensing of conditions which make convection to high altitudes likely in infected areas
Intensity and size of spore cloud	Data on all areas currently infected A Elapsed time since infection B Temperature conditions since infection C Moisture conditions since infection D Size of areas infected
Winds to move spore cloud	A From satellite sensing of cloud velocity and altitude B From ground meteorological data
Location of rains forecast within wind trajectory which will deliver spores	Two-day weather forecasts
Delivery of spores	Satellite sensing of A Precipitating clouds B Ground meteorological data

EXHIBIT III-26 (Continued)

Component of Model Each Resolution Element	Required Sensings
Confirmation of soil, weather, rust interactions to improve assessment of rust growth	Satellite sensings of temperature and moisture conditions Ground data
Correlation between rust severity and damage, and prediction of rust spread pattern	

In order to clarify the manner in which the satellite-supported model would contribute to the decisionmaker's knowledge that unusual conditions favoring rust have occurred or will occur, the National Rust Spread Scenario and the Rust Observation, Analysis, and Control Scenario have been summarized in the following text

As events occur during the growth period of wheat and the spreading of rust, each component of the model will be established from information concerning each event The Rust Observation Analysis and Control Scenario describes a hypothetical analysis which took place on April 10 Exhibit III-27 shows the relationship of the events as they occurred to the components of the model, even as long as 10 months before a farmer needs to make a spraying decision The satellite-supported system was able to make a number of observations of events as they occurred Each event contributed to a model component that was affected by that event The system recorded and analyzed all the information on the events Some of the events were directly related to Shawnee and Ford Counties in Kansas in order to more effectively detail the scenario Each of the observations of these events accumulated to establish a highly reliable model component Other observations or sensings were only of historical relevance These observations were used to refine the statistical data on the pattern of nature by which the system performs its analyses A complete listing of all the events and their relevance is shown in Appendix I. VI.

As described in the Rust Observation Analysis and Control Scenario, when the system could predict that damage at harvest would be greater than 25 percent (if rust occurred 40 to 70 days before harvest), an alert was issued for Ford and Shawnee Counties, Kansas By March 1 when the alert was declared, the system had established clearly the factors of analysis upon which this alert for Ford and Shawnee Counties was based Exhibit III-28 shows the number of sensings of events which were incorporated into the analysis as each event occurred The reiterative updating of the components of the model by these sensings produced the March 1 prediction A similar process, completed in a short time, enabled the system to predict the arrival of spores at Ford and Shawnee by April 12

EXHIBIT III-27 RELATIONSHIP OF EVENTS FROM SCENARIO TO COMPONENTS OF THE MODEL

Phase Relative to Shawnee and Ford Counties	Time	Event From Scenario (See Appendix)	Component of Model Which Is Affected by This Event
Post harvest	Aug 1 - Aug 15	Heavy wheat rust infection in northern U S. and Canada and on volunteer grasses in central and southern U S and in Mexico Most prevalent rust is identified as stem rust 15-B.	Location of rust Type of rust Race of rust Intensity and size of potential spore clouds Probable damage to wheat Confirmation, assessment, and prediction
Postharvest	Aug. 18 - Aug 25	Temperature of volunteer grasses in some areas increases Weather is warm and moist	Location of rust Assess growth of rust
Postharvest	Sep 10 - Sep 20	Dry weather over Great Plains Temperatures of plants in large areas of Great Plains have increased Local convection carries spores into the air	Soil moisture Size and intensity of spore concentration Spore cloud development
Planting	Sep 1 - Nov 1	Winter wheat is planted and grows until vernalization Varieties in Shawnee and Ford are X, Y, and I	Wheat areas Variety of wheat Stage of growth Probable date of harvest
Postplanting to	Oct 1 - April 10	Fall and winter weather includes above-normal precipitation and higher-than-normal temperatures in Mexico and Texas	Probable damage Soil moisture

EXHIBIT III-27 (Continued)

Phase Relative to Shawnee and Ford Counties	Time	Event from Scenario (See Appendix)	Component of Model Which Is Affected by This Event
Postplanting to Growing Season	Feb 1 - April 10	Heavy rust infection in Mexico and Texas over large areas	Location of rust Intensity and size of probable spore concentration
Postplanting to Growing Season	Feb 1 - April 10	Most prevalent form of rust is stem rust 15-B to which varieties X, Y, and I are susceptible	Type and race of rust
Postplanting to Growing Season	Oct 1 - March 10	Fall and winter in central and northern Great Plains include above-normal precipitation	Soil moisture
Growing Season	March 1	Winter wheat emerges in Shawnee and Ford	Wheat areas State of growth of wheat Probable date of harvest Probable damage from rust
Growing Season	Feb. 10 - April 10	Wheat areas of Kansas and northern Great Plains experience below-normal temperatures. Harvest is predicted for June 17	Stage of growth of wheat Probable date of harvest Probable damage from rust
Growing Season	April 2 - April 10	Dry weather over Mexico and Texas Local convection carries rust into the air	Soil moisture Spore cloud development
Growing Season	April 6 - April 12	Air mass from Mexico moves north across the Great Plains Rains are predicted to deliver spores to growing winter wheat in Oklahoma and Kansas	Winds to move spores Location of rains within wind trajectories Delivery of spores

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Event and Timing \ Component	Wheat Areas (1)	Variety of Wheat (1)	Cumulative Soil Moisture (1)	Stage of Wheat Growth (1)	Probable Conditions Preharvest (1)	Probable Date of Harvest (1)	Rust Location, Extension, and Severity (1)	Type and Race of Rust (1)	Probable Damage (1)	Spore Cloud Development (2)	Intensity Size of Spore Cloud (2)	Winds To Move Spore Cloud (2)	Location of Rains (2)	Surveillance and Confirmation (3)	Delivery of Spores (3)	Correlation and Comparison (3)
Aug 1 - Aug 15, Heavy Rust 15-B					1		2	2								
Aug 18-25, Temperature of Grasses Increases					1		2									
Sep 10-20, Dry Weather			2													
Sep 1 - Nov 1, Planting	8	1		8	1	8										
Oct 1 - Apr 10, Greater Than Normal Precipitation and Higher Temperatures in Mexico and Texas					1											
Feb 1 - Apr 10, Heavy Rust Infections in Mexico and Texas					1		95				95					
Feb 1 - Apr 10, Stem Rust 15-B Is Most Prevalent in Mexico and Texas					1			95								
Oct 1 - Mar 10, Great Plains Above Normal Precipitation			40		1											
Feb 10 - Apr 10, Below Normal Temperatures in Kansas				40	1	40			40							
Mar 1, Winter Wheat Emerges				1	1	1			1							
Apr 2 - 10, Dry Weather Over Mexico - Texas, Spores Rise										5						
Apr 6 - 12, Air Mass Moves North, Rains Predicted												6	6			
Cumulative Number of Sensings	8	1	42	49	9	49	99	97	41	5	95	6	6			

Notes (1) With these components, a prediction of damage at harvest, given the arrival of spores on any day before harvest, is made on March 1 Because this prediction set probable rust damage above 25 percent, if 15-B occurred 40 to 70 days before harvest, Shawnee and Ford were put on alert

(2) With these components, a prediction of the arrival of spores in Ford and Shawnee by April 12 is made on April 10

(3) To be used for prediction for areas in the next sector

EXHIBIT III-28 WHEAT RUST ANALYSIS OF FORD AND SHAWNEE COUNTIES - APRIL 10
TIMING AND NUMBER OF SENSINGS AS EACH EVENT OCCURRED

The accuracy with which these components of the model are established depends primarily upon the ability of the satellite system and ground observers to observe repeatedly the natural phenomena which affect wheat and wheat rust These repeated sensings or observations, as described in Exhibit III-29, are the bases for the establishment of some components as early as November 1 Other components of the model, such as stage of wheat growth in the example, cannot be determined until March 1 when the winter wheat reemerges from the soil The components indicating delivery of spores cannot be stated until the spore cloud has developed, April 10 in the example Finally, some components that will apply to predictions for areas in the next sector will be established by verification of delivery of spores, surveillance, correlation, and comparison on April 11 and after

The discussion developed in the water management case (and referred to in the wheat inventory/yield case) on the advantages of repeated observations, bottom recognition, and other systems techniques to improve the overall accuracy of the satellite-assisted system are applicable here These techniques, based on earth sciences developmental R&D, appear to be capable of complementing the developmental R&D required to prove state-of-the-art capabilities of MSS, TV, and radar at satellite altitude

2. Total Benefits

Losses due to wheat stem rust vary greatly from year to year, from merely trace damage to very high levels, as illustrated in Exhibit III-30. Although the fluctuations in leaf rust are less spectacular, there is considerable variation in the damage resulting from this disease. The annual average losses for stem rust and leaf rust for the 10-year period 1957-1966 amounted to $154 million.[1] The satellite-assisted information system benefits are the monetary value of bushels of wheat saved by correct chemical spray decisions based upon satellite-gathered information.

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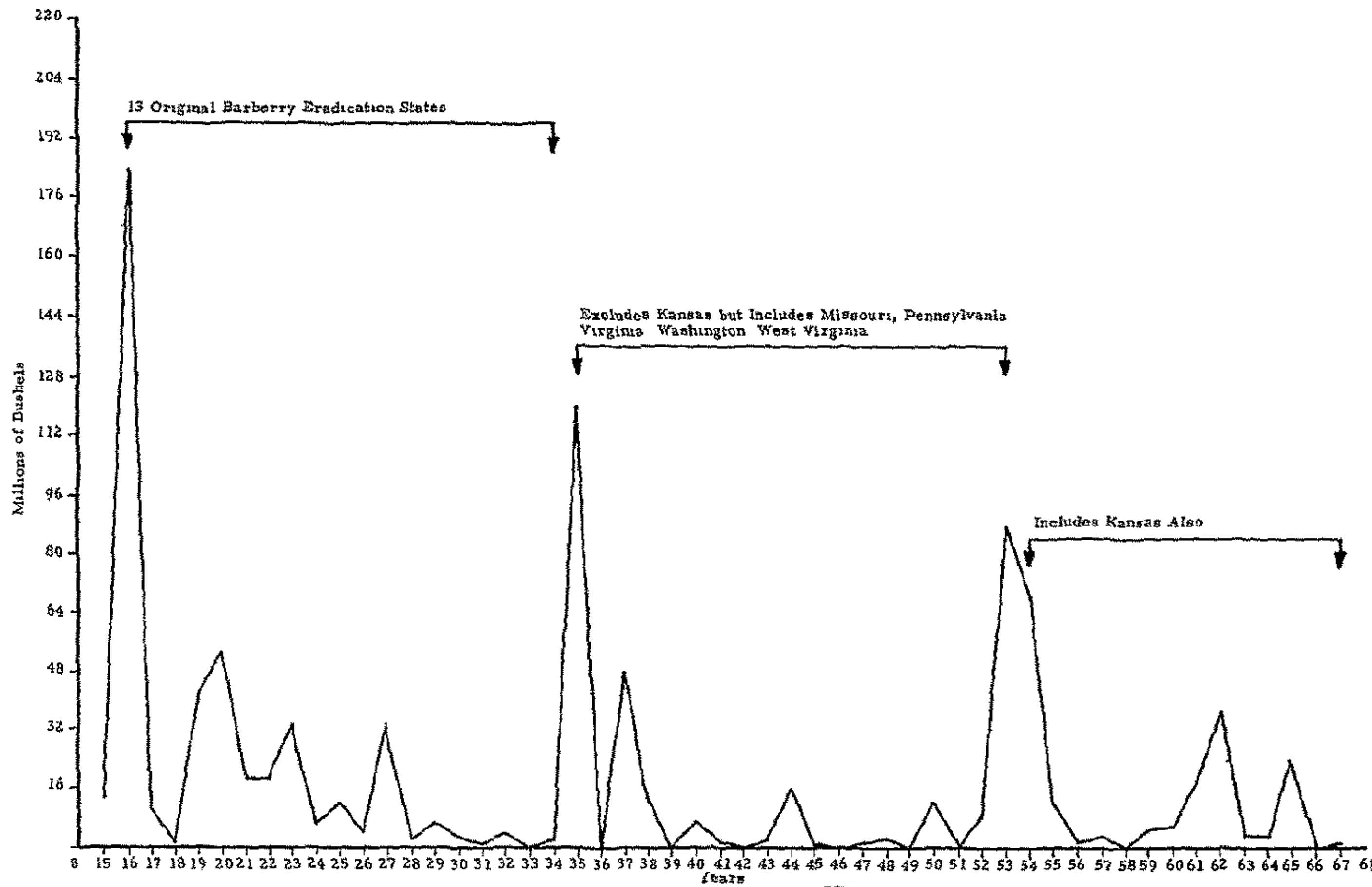
[1] U.S. Department of Agriculture, Agricultural Research Service, Losses in Agriculture, Handbook No. 291, U.S. Government Printing Office, (Washington, 1965), and U.S Department of Agriculture, Agricultural Statistics 1967, U.S. Government Printing Office (Washington, 1967).

EXHIBIT III-29 SEQUENTIAL DEVELOPMENT OF COMPONENTS OF THE MODEL AND SYSTEM PREDICTIONS

Factor of Analysis	Date Component Is Established	Number of Sensings (Allowing for Obscurity Degradation)
Wheat Areas	Nov 1	8
Variety of Wheat	Nov 1	3
Rust Location, Extension, and Severity	Mar 1	79
Type and Race of Rust	Mar 1	79
Stage of Wheat Growth	Mar 1	41
Soil Moisture	Mar 1	35
Probable Damage if Rust Occurs April 1 - May 1	Mar 1	41
Declare Preliminary Rust Alert March 1		
Spore Cloud Development	April 10	5
Probable Intensity of Spore Cloud	April 10	145
Winds To Move Spore Clouds	April 10	6
Rains Predicted	April 10	6
Issue Prediction of Spore Arrival April 10		
Delivery of Spores Surveillance Correlation and Comparison	April 11 and After	

Note (1) The repetition of accurate sensings reduces errors to very low levels, such as $(0\ 01)^8$ Some of the sensings, moreover, reinforce the ability of the system to sense other related phenomena The observation of soil moisture by satellite sensing, for example, will confirm estimates of soil moisture made by monitoring precipitation The entire technique of predicting the spread of rust, furthermore, will be improved by the satellite's direct sensing of phenomena that confirm the model's predictions

EXHIBIT III-30 BUSHELS OF WHEAT LOST FROM STEM RUST



The projected 1971-1990 benefits for the United States and 15 selected countries are summarized in Exhibit III-31.

EXHIBIT III-31. BENEFITS FROM SATELLITE-ASSISTED CONTROL OF WHEAT RUST (MILLIONS OF DOLLARS IN CROPS SAVED).

Countries	20-Year Benefits Discounted		
	7-1/2%	10%	12-1/2%
United States	$1,173	$ 967	$ 811
Selected Other Countries	5,745	4,732	3,957
Total	$6,918	$5,729	$4,768

The United States benefits were estimated by determining what the maximum annual benefit in terms of crops saved might be. Then the costs of control were subtracted. Finally, the benefits were adjusted according to the capability of the satellite system to provide needed information and the rate at which farmers might be expected to adopt the information system control techniques.

The gross United States annual benefits were estimated to be $154 million based on data in the report cited above and the assumption that 100 percent control would eventually be achieved.

Control costs were estimated to be 9 percent of the value of the crop saved (\$13.6 million ÷ \$154 million). These control costs are based upon the following strategy of heavy spraying in the southern United States.

The pathological characteristics of the rust multiply the effectiveness of control because of the geographic cycle of the disease (winters in the south, summers in the north) and the dependence of epidemics upon the movement of spore clouds from south to north during the growing season With the satellite sending of infected areas early before the production of spore clouds, northern production areas can gain protection

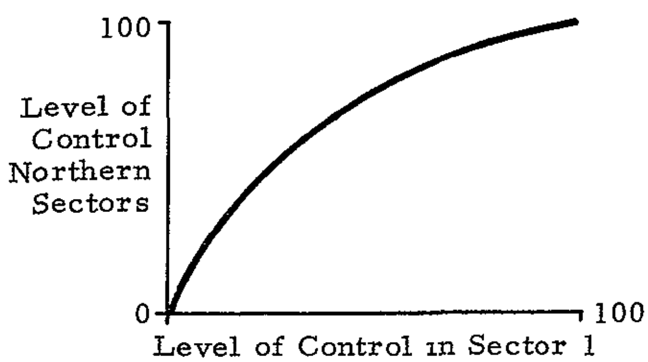
by the treatment of the southern production areas. Since stem rust winters only in Texas and Mexico, treatment of a minimum acreage would give widespread protection. Treatment in Texas would provide control of the spread of rust from Mexico (assuming no control is effected in Mexico proper) by providing a wide "buffer zone." Spores produced in Mexico would largely fall in Texas and be killed by the protectant fungicide. Those spores that are blown beyond the buffer zone will tend to lose their viability before reaching the northern production area. Extensive treatment would not be required every year since serious infections only occur on the average of one year in three.

By controlling the spread of rust in the wintering area, the cost of control would be kept to a minimum. Even if all of the wheat acreage in Texas were treated each year, the cost of treatment would be low compared to the potential benefits ($6 80 x 6 million acres = $41 million) A more reasonable cost would seem to be for one-third of the acreage, or one-third of the years ($6.80 x 2 million acres = $13.6 million).

The $6.80 per acre control costs are based on the following calculations

2 applications per season at $1.50	$3.00
2 pounds of chemicals per application at .95	3 80
Total spray cost per acre	$6.80

Since the major production area for wheat lies north of Texas, control in Texas would produce multiple total benefits to the industry Varying effectiveness of control in Texas would have inverse effects on the northern production areas A relatively low level of control in Texas would give a level relatively higher in the northern states because of the exponential pattern of development of the disease



The final adjustment made to United States benefit figures was based on the capability of the satellite system to provide the information needed for effective control and the rate at which farmers might be expected to adopt the information system control techniques. (Details of these calculations are explained in Appendix I VII) As the prediction technique improves and the farmer participation rate grows, the system should reach 95 percent effectiveness by 1976. The benefits shown do not reach 100 percent effectiveness because information diffusion researchers report that it is nearly impossible to get 100 percent participation in order to virtually wipe out the threat of rust epidemics.

It should be emphasized that because current estimates of losses are believed to be underestimated, the benefits of effective chemical control may actually be larger than those calculated for this study

The extrapolation of United States benefits to the world was made by selecting 15 major wheat producing countries which might participate and benefit from the use of a satellite information system. The average annual wheat production of these countries from 1960 to 1966 was multiplied by the loss factor of 6.5 percent, the U.S Department of Agriculture estimate of wheat rust losses in the United States. This quantity of wheat estimated to be lost to rust was then multiplied by the average domestic price for each country during the same time period This value was also reduced by the estimated cost of spraying (in absence of foreign spray costs, the U.S costs were used) and the satellite capability and farmer participation rates (explained in Appendix I. VII)

In addition to rust control in wheat, other fungous diseases such as septoria and powdery mildew can be controlled in wheat and other small grains through the same system Spraying for rust will kill the other diseases at the same time However, because the development patterns of the other diseases are different, they can not be as thoroughly controlled by the strategy of spraying in the southern United States. For effective control, a more extensive geographic spray program would have to be undertaken

Estimates of the benefits from eliminating these other fungous diseases are shown in Exhibit III-32. The crops in which losses can be prevented include wheat, oats, barley, and rye The benefits shown include the control of rusts in grains other than wheat but exclude the wheat rust benefits which were shown in Exhibit III-31. It should be noted that these benefits are gross benefits because the spray control costs have not been subtracted. Such a subtraction was precluded by the difficulty in estimating the number of acres that would have to be sprayed Also, a detailed annual analysis of satellite capability and farmer participation rates was not undertaken For this reason, several levels of control were assumed.

3 Total Costs

The water management system configuration, because of the timing and orbiting conditions, will meet the requirements of the wheat rust case The costs are therefore the same. Spray costs are treated in the previous subsection and are subtracted from the total benefits for convenience of presentation.

4 Sensitivity

The satellite sensor possesses high capability to observe the various phenomena that indicate the growth and spread of wheat rust during critical periods (see Exhibit III-4) Each of the satellite sensings and ground observations has a high degree of accuracy, and repeated sensings reduce errors to insignificant levels. Within the current state-of-the-art of sensors, 15 percent effectiveness of the system is estimated for 1971 because of limitations in the resolution of sensors that detect the location, extension, and severity of rust and because it is reasonable to assume that full participation in spraying operations will develop only as the usefulness of the system has been demonstrated

There are certain improvements in the satellite-borne sensors that would enable the system to perform its operations more efficiently

EXHIBIT III-32 ESTIMATED VALUE OF GRAIN CROPS OTHER THAN WHEAT SAVED WITH SELECTED LEVELS OF CONTROL, UNITED STATES AND 15 SELECTED COUNTRIES, 20 YEARS (Millions of Dollars in Crops Saved)

Source of Loss	Level of Control 10%	40%	70%	95%	100%
United States					
Septoria	$3 9	$15 4	$27 0	$36 7	$38 6
Powdery Mildew	1 1	4 6	7 9	10 8	11 4
Crown Rust[1]	2 4	9 6	16 9	22 9	24 1
Stem Rust[1]	1 5	6 1	10 7	14 5	15 3
Total	$8 9	$35 8	$62 6	$84 9	$89 4
Total Discounted					
7-1/2%	4 9	20 0	34 2	46 5	49 0
10%	4 2	16 7	29 3	39 8	41 9
12-1/2%	3 6	14 6	25 5	34 6	36 4
15 Selected Countries					
Septoria	$18 6	$74 3	$130 0	$176 4	$185 7
Powdery Mildew	7 2	28 9	50 5	68 5	72 1
Crown Rust[1]	7 5	29 8	52 2	70 8	74 6
Stem Rust[1]	5 6	22 5	39 3	53 4	56 1
Total	$38 9	$155 4	$272 0	$369 2	$388 6
Total Discounted					
7-1/2%	$21 3	$85 2	$149 0	$202 3	$212 9
10%	18 2	72 8	127 4	172 9	181 9
12-1/2%	15 8	63 3	110 8	150 4	158 3

[1] Rust Damage to wheat excluded

- Development of a sensor that could sense the presence of spores in the air
- Development of better signatures for rust at low levels of severity

Most of the significant improvements in the system, however, can be made through research by defining with greater accuracy certain relationships between wheat, soil, weather, and rust

- The limits of all the manifestations of disease that would point to more sensings of disease, which could be made with state-of-the-art sensors, complete studies of these "symptoms" would enhance the value of current sensors
- Precise determination of the characteristics of the spread of rust, the hypothetical "spore cloud," for example, needs further study
- Determination of the altitude and time at which spores lose their viability
- Determination of the relative importance of rain, local winds, and air masses as methods of delivery of the spores
- Establishment of more ground stations to collect and analyze data on rust spread, development, and damage under natural conditions
- Development of a systemic spray to protect wheat plants against fungi diseases

In general, the conclusions as to system sensitivity that were presented in the wheat inventory/yield case are applicable here. The system will be sensitive to basic R&D costs of pushing the sensor state-of-the-art and insensitive to use of equipment below expected state-of-the-art capabilities at altitude The earth sciences must be supported to accomplish the integrated system herein proposed

5 Information Alternatives

The wheat rust mission requires twice-a-day coverage of the estimated 331,000-square-mile wheat-growing area in North America To provide this coverage by aircraft, it would take 26 T-39's calculated as follows

$$\frac{\text{area covered x frequency/month}}{\text{monthly coverage per T-39}} = \frac{331{,}000 \times 60}{777{,}000} = 26$$

The T-39's monthly coverage is greater for the agriculture case since it is assumed that the mean elevation of the wheat-growing area (2,500 feet) is much lower than that of the hydrology area (6,000 feet) Given the T-39's service ceiling of 42,000 feet, the swath width for the agriculture case is 25 9 miles as compared to 23 6 miles for hydrology This results in coverage of 777,000 square miles per month for agriculture and 708,000 square miles for hydrology The total systems cost of this alternative is approximately $410 million over the 1970-1990 time period [1]

The cost and performance comparison of competing satellite and aircraft systems for the agriculture wheat rust application is shown in Exhibit III-33 The aircraft system designed to meet wheat rust performance requirements in North American wheat areas alone is, of course, more favorable on a cost/performance basis than the satellite designed for use only in the United States There are, however, about 0 8 million square miles of wheat in the world. Even if overflight of an area twice this large is required to survey all wheat, the satellite system is noncompetitive However, the rust case can ride as a secondary beneficiary of the water management case

[1] These costs are based on coverage of the entire United States wheat producing area. Therefore, the costs shown are considerably larger than would be needed under the strategy of spraying heavily in the Southern United States which would yield effective control and benefits as discussed in Section III D 2

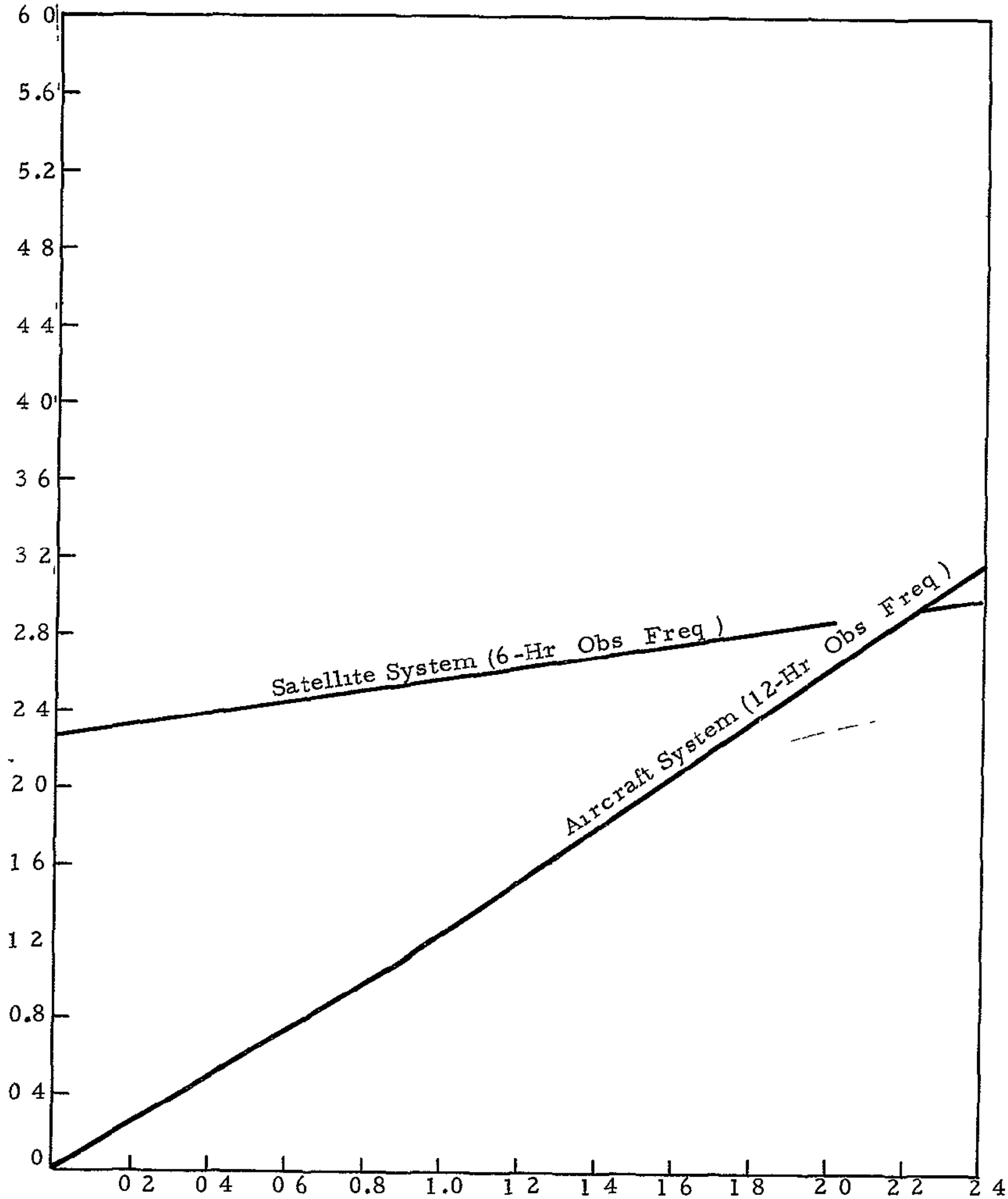


EXHIBIT III-33 SATELLITE AND AIRCRAFT SYSTEM COST/PERFORMANCE COMPARISON (WHEAT RUST)

6 Noninformation Alternatives

Current efforts for control of wheat rust are centered on the development of varieties of wheat that are resistant to identified races of rust Generally, there is a time lag of from 8 to 15 years between the initial identification of a potentially dangerous wheat rust race and the availability of commercial quantities of a new wheat variety that is resistant to that race Thus, it is extremely important that new, dangerous wheat rust races be identified as early as possible so that new varieties of wheat can be made commercially available before any individual strain of rust can become widespread.

Currently, the Wheat Investigation Laboratory of the U S Department of Agriculture conducts a continuous survey of wheat rust, annually identifying as many as 300 new races of rust The lab annually publishes pathogenicity reports describing each of these new strains, of the hundreds considered, usually five to 10 are deemed potentially very dangerous These strains are usually identified early enough so that the lead time before they become widespread is at least equal to the new-variety development cycle After identification and selection, a breeding program is then initiated to develop a variety of wheat resistant to each of the selected races of dangerous rust The breeding program is a joint venture among the Wheat Research Lab, various state agricultural research stations, and commercial seed companies, the cost of research is borne approximately equally by these three groups It is estimated that each spends about $1 5 million so that the current wheat research program in the United States costs about $5 million in current 1968 dollars

There are many cases in which a developed variety of wheat never is used on a commercial basis because the race of rust for which it was developed never spreads or becomes a problem Conversely, there are some instances where particular strains deemed not dangerous do spread and become important or selected strains spread faster than resistant varieties become available. In these instances, if losses of two bushels per acre are projected, the wheat farmer should spray his fields with a protectant chemical spray. This, of course, required advance warning of the projected loss as no eradicative spray exists, but the control of rust depends on the application of a protectant spray as discussed in subsection III D 1 An alternative to chemical control is to increase the level of wheat research and to breed more new varieties of resistant wheat However, the problem of the time constraint remains. That is, it takes 8 to 15 years to develop a new variety, and it may or may not have a long-term value. A new race of rust can often affect the variety shortly after its introduction, so it no longer is an effective protection

In every case where new, resistant varieties of wheat are made commercially available, the yields and quality are at least as good as the old variety that it is to replace New varieties are, in fact, constantly improving in yield due to this stipulation, and often a new variety is useful over a wider geographic region Thus, a new resistant variety developed for North Dakota might later be planted widely in Washington because of either resistance or some other desirable characteristic

It is estimated that about 25 percent of worldwide wheat research is currently accomplished in the United States In addition to that actually done in the United States, a great deal of other Free World research is paid for by United States funds Much of the wheat research accomplished in Latin American countries, for instance, is supported by Rockefeller and Ford Foundation grants The United States Department of Agriculture also supports research in many countries Many varieties developed in the United States become important in foreign countries

The conclusion appears to be that a breeding program may be, at least, partially effective The costs of implementing an augmented program are modest The time lag in evaluating effectiveness, however, may be a decade or so The space program should not wait that long to initiate its contribution to resolving agricultural stress problems It would appear that both programs should be undertaken until more definite information on potential success or failure can be obtained

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IV TECHNOLOGICAL PHASING

Exhibits IV-1 through IV-6 are the dependency matrices that relate the sensors to the measurements, the measurements to the forecast, and the forecasts to the benefits The numbers associated, indicate an estimated contribution of each factor to its corresponding element The exhibits show the Earth Resource Technological Satellite system and the Advanced I system, indicating the expected improvements in sensor capability

Exhibit IV-7 outlines the difference between ERTS and Advanced I to determine what possible operational level might be expected from the limited configuration of ERTS

No effort to phase the third-generation system, Advanced II, is made here in view of the fact that resolutions in Advanced I are sufficient for the requirements of the three benefit areas

The benefits to the wheat inventory yield model have been calculated on the Advanced I operational system based on the expected resolutions and system configuration described in the water management case The ERTS sensors as shown in Exhibit IV-7 are not intended to constitute an operational system but rather a research effort If, however, the data from the ERTS system were analyzed and disseminated in a similar way as in the operational system, it would yield some portion of the benefits The degrading of the benefits is done on the basis of fewer sensors, degraded resolution, and less frequent observations The frequency of observations is the most critical difference between the systems The degradation of benefits, therefore, is mostly dependent on the criticality of timing for the particular decision

In the case of savings to the Commodity Credit Corporation, unit costs, agribusiness savings, foreign assistance, and less developed countries, weekly estimates are a substantial aid to the current system The loss in frequency would be reflected in the accuracy of yield estimates, but with an observation once per week, only an estimated 10 percent would be lost

In the case of benefits from production options, timing is far more critical. The accuracy of the information requires monitoring of moisture to determine soil moisture, and an accurate estimate of soil moisture is necessary for the farmer to exercise the options In this case probably 75 percent would be sacrificed

The system design for detection and control of wheat rust is highly dependent on observation of complex conditions that affect the development of the pathogen The timing and degree of infection are extremely important to the farmer's decision to spray or not to spray The usefulness of ERTS to wheat rust is severely limited unless the strategy for control is changed If, however, the alternative approach of creating a buffer zone to prevent the northerly progression of rust were employed, the effectiveness of ERTS would be increased, that is, if zone 1 were controlled the gross benefits would remain high, but the spraying costs would be increased to result in a smaller net benefit. Without the satellite-assisted system to monitor the rest of the country, the tiered buffer strategy would probably fail Probably not more than 15 percent of the potential benefit could be realized from this approach

The basis for the degrading of the benefits through water management from those calculated for Advanced I to those expected from ERTS is the same as for the other cases, i e , fewer sensors, degraded resolution, and less frequent observations Frequency of observation and timing of the information are especially important in benefit areas such as flood control and interreservoir coordination for power generating purposes where the rapid melting of low-lying snow and rainstorms may have sizable and sudden effects on these operations, thus, the almost total degrading of benefits in these areas for ERTS since it will not make passes frequently enough to effectively reduce the uncertainty of short-term forecasts Interreservoir and flood control will be most seriously affected by the lack of accurate short-term forecasts Thus only about 5 percent of the benefits achieved under ADVANCED I are likely to be realized under ERTS Drawdown strategy hedge irrigation and recreation are also quite dependent upon short-term forecasts but can employ medium to long-range to some advantage The benefits in this area, however, are likely to be only 25 percent of that realized under ADVANCED I in using ERTS

EXHIBIT IV-1 REGIONAL WATER MANAGEMENT - EARTH RESOURCES TECHNOLOGICAL SATELLITE

MANAGEMENT/BENEFIT AREAS

MANAGEMENT/BENEFIT AREAS	Seasonal Snowmelt Runoff	Seasonal Rainfall Runoff	Streamflow Surface	Streamflow Groundwater	Streamflow Maxima	Streamflow Minima	Load Variation (Power)
Drawdown-Refill	2	2	2	3	3	2	2
Inter-Reservoir	3	3	2	3	3	3	2
Generation Efficiencies	3	3	2	3	2	2	2
Flood Control	2	2	3	3	2	3	4
Irrigation	2	2	3	2	3	3	4

(FORECASTS AND/OR) ELEMENTS OF MANAGEMENT DECISIONS

Seasonal Snowmelt Runoff	Seasonal Rainfall Runoff	Streamflow Surface	Streamflow Groundwater	Streamflow Maxima	Streamflow Minima	Load Variation (Power)	MEASUREMENTS	SENSORS TV	SENSORS MSS	SENSORS Radar	SENSORS MWR	SENSORS IR Scanner
3	3	2	2	2	2	4	Streamflow (Antecedent)	3(A)	4(A)	3/4(A)		
4	2	2	2	2	3/4	4	Rainfall	3(L)	4(A)	2(O)	3/4	3
2	4	3	2	3	3	4	Snow Area - High Level	2(N)	3(N)	2/3(O)	3	3
3	4	3	3	2	3	4	Snow Area - Low Level					
2	4	3	2	3	3	4	Snow Water Equivalent - High	3(A)	3(A)	2/3(O)	3/4	3
3	4	3	3	2	3	4	Snow Water Equivalent - Low					
3	4	3	3	3	3	4	Snow Temperature - High		2		3/4	2
4	4	3	3	3	3	4	Snow Temperature - Low					
3	4	3	3	3	3	4	Snow Albedo - High	2/3(A)	2/3(A)			
4	4	4	4	3	3	4	Snow Albedo - Low					
3	3	3	3	3	3	2	Air Temperature		2(P)		2	2/3
3	3	3	3	3	3	4	Ground Temperature		2(P)		3	2
3	2	2	2	2	3	4	Soil Moisture	2/3(L)	3/4		2/3	3
2	2	2	3	3	3	4	Evapo Transpiration		3(R)		3	3
4	3	4	4	4	4	2	Cloud Cover	1/2	3(A)			2/3

LEGEND

1 *Sufficient*

2 Major Contribution

3 Contribution

4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT IV-2 WHEAT INVENTORY - EARTH RESOURCES TECHNOLOGICAL SATELLITE

MANAGEMENT AREAS/BENEFITS	Crop Identification	Crop Area & Location	Stress Identification	Stress Severity	Stress Location	Stage of Growth	Ground Conditions	Weather
1 CCC Savings	2	2	2	2	2	2	2	2
2 Producers' Options	2	2	3	2	2	2	2	2
3 Lower Unit Costs	2	2	2	2	2	2	2	2
4 Agribusiness Savings	4	4	3	3	2	4	3	2
5 Lower U S Foreign Assistance	2	2	2	2	2	2	2	2
6 Benefits in Lesser Developed Countries	2	2	2	2	2	2	2	2

FORECASTING

Crop Identification	Crop Area & Location	Stress Identification	Stress Severity	Stress Location	Stage of Growth	Ground Conditions	Weather	MEASUREMENTS	SENSORS TV	MSS	Radar	MWR	IR Scanner
4	4	3	3	3	3	4	2	Minimum Daily Temperature	4	2	4	4(A, H)	2
4	4	3	3	3	3	3	2	Maximum Daily Temperature	---	14	---	1, 14	14
4	4	2	2	2	2	2	2	Rainfall	3(B C I)	3(B C I)	2(B C I) 5,6,15	3(B C I) 5,6,15	3(B C I)
4	4	2	2	2	2	2	3	Soil Moisture	3 (B C)	3(B C)	2/3(B C)	3(A B C)	3(B C)
2	2	2	2	2	3	4	4	Plant Temperature	4	2/3(A F)	4	4(A)	2/3(A F)
3	3	2	2	2	2	4	4	Respiration	4	4	4	4	4
3	3	2	2	2	2	4	4	Evapotranspiration	4	3(A, K) 1 18	4	4	3(A K)
1	1	4	4	4	4	4	4	Acres of Wheat	2(D G)	3/4(A G) 1 11	2/3(D)	4(A)	3(A E)
4	4	3	2	3	2	4	4	Density (% ground covered by wheat)	3	4	4(E)	4(A)	4(E)
4	4	2	2	2	4	3	2	Wind (Direction and Velocity)	4	4	4	4	4

LEGEND

1 Sufficient

2 Major Contribution

3 Contribution

4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT IV-3 WHEAT RUST CASE - EARTH RESOURCES TECHNOLOGICAL SATELLITE

	FORECASTING: Crop Identification	Crop Area and Location	Crop Vigor	Stress Identification	Stress Severity	Stress Location	Infection Probabilities						
MANAGEMENT AREAS/BENEFITS													
Increased Yields	3	3	2	2	2	2	2						
									SENSORS				
								MEASUREMENTS	TV	MSS	Radar	MWR	IR Scanner
	4	4	3	3	3	3	2	Minimum Daily Temperature	4	2(H)	4	4(A, H)	2(H)
	4	4	3	3	3	3	2	Maximum Daily Temperature					
	4	4	2	3	3	2	2	Rainfall	3(B C, I)	3(B C I)	2(B C I, J)	3(A B C, I)	3(B C I)
	4	4	3	3	2	2	2	Soil Moisture	3(B, C)	3(B C)	2/3(B C)	3(A B C)	3(B C)
	2	2	2	2	2	2	4	Plant Temperature	4	2/3(A F)	4	4(A)	2/3(A F)
	3	3	3	2	2	2	2	Respiration	4	4	4	4	4
	3	3	2	2	2	2	2	Evapo-Transpiration	4	3(A K)	4	4	3(A K)
	1	1	4	4	4	4	4	Acres of Wheat	2(D G)	3/4(A G)	2/3(D)	4(A)	3(A E)
	4	4	4	4	3	2	2	Wind (Direction and Velocity)	4	4	4	4	4

LEGEND

1 Sufficient

2 Major Contribution

3 Contribution

4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT IV-4 REGIONAL WATER MANAGEMENT - EARLY OPERATIONAL SYSTEM

MANAGEMENT/BENEFIT AREAS	Seasonal Snowmelt Runoff	Seasonal Rainfall Runoff	Streamflow Surface	Streamflow Groundwater	Streamflow Maxima	Streamflow Minima	Load Variation (Power)
Drawdown Refill Strategy	2	2	2	3	3	2	2
Inter-Reservoir Coordination	3	3	2	3	3	3	2
Head Efficiencies and Hedge	3	3	2	3	2	2	2
Flood Control	2	2	3	3	2	3	4
Irrigation	2	2	3	2	3	3	4

(FORECAST AND/OR) ELEMENTS OF MANAGEMENT DECISIONS

Seasonal Snowmelt Runoff	Seasonal Rainfall Runoff	Streamflow Surface	Streamflow Groundwater	Streamflow Maxima	Streamflow Minima	Load Variation (Power)	MEASUREMENTS	SENSORS: TV	MSS	Radar	MWR	IR Scanner
3	3	2	2	2	2	4	Streamflow (Antecedent)	3 (A)	3 (A)	3 (A)		
4	2	2	2	2	3	4	Rainfall	3	3/4 (L)	2	3 (T)	3
2	4	3	2	3	3	4	Snow Area - High Level	2	2/3 (N)	2/3	3	3
3	4	3	3	2	3	4	Snow Area - Low Level					
2	4	3	2	3	3	4	Snow Water Equivalent - High	2/3 (A)	2/3 (A)	2/3	3 (S)	3
3	4	3	3	2	3	4	Snow Water Equivalent Low					
3	4	3	3	3	3	4	Snow Temperature High		2		3 (S)	2
4	4	3	3	3	3	4	Snow Temperature - Low					
3	4	3	3	3	3	4	Snow Albedo High	2/3	2 (S)			
4	4	4	4	3	3	4	Snow Albedo - Low					
3	3	3	3	3	3	2	Air Temperature		2 (T)		2 (T)	2 (T)
3	3	3	3	3	3	4	Ground Temperature		2 (T)		2/3 (T)	2 (T)
3	2	2	2	2	3	4	Soil Moisture	2/3	3 (L)		2 (S)	2/3 (T)
2	2	2	3	3	3	4	Evapotranspiration		3 (U)		2/3 (U)	2/3 (U)
4	3	4	4	4	4	2	Cloud Cover	1/2	1/2 (T)			1/2 (U)

LEGEND

1 Sufficient
2 Major Contribution
3 Contribution
4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT IV-5 WHEAT INVENTORY - EARLY OPERATIONAL SYSTEM

MANAGEMENT AREAS/BENEFITS	Crop Identification	Crop Area and Location	Stress Identification	Stress Severity	Stress Location	Stage of Growth	Ground Conditions	Weather
1 CCC Savings	2	2	2	2	2	2	2	2
2 Producers' Options	2	2	3	2	2	2	2	2
3 Lower Unit Costs	2	2	2	2	2	2	2	2
4 Agribusiness Savings	4	4	3	3	2	4	3	2
5 Lower U S Foreign Assistance	2	2	2	2	2	2	2	2
6 Benefits in Lesser Developed Countries	2	2	2	2	2	2	2	2

FORECASTING

Crop Identification	Crop Area and Location	Stress Identification	Stress Severity	Stress Location	Stage of Growth	Ground Conditions	Weather	MEASUREMENTS	SENSORS TV	MSS	Radar	MWR	IR Scan.
4	4	3	3	3	3	4	2	Minimum Daily Temperature	4	1 (H)	4	2 (A H)	1 (H)
4	4	3	3	3	3	3	2	Maximum Daily Temperature					
4	4	2	2	2	2	2	2	Rainfall	3 (B C I)	2 (B C I)	1/2 (B C I J)	2 (A B C I)	2 (B C I)
4	4	2	2	2	2	2	3	Soil Moisture	3 (B C)	2 (B C)	2 (B C)	2 (A B C)	2/3 (B C)
2	2	2	2	2	3	4	4	Plant Temperature	4	1 (AF)	4	3/4	1 (A)
3	3	2	2	2	2	4	4	Respiration	4	4	4	4	4
3	3	2	2	2	2	4	4	Evapotranspiration	4	2 (A K)	4	3/4 (A K)	2 (A K)
1	1	3	3	3	2	4	4	Acres of Wheat	2 (D G)	1	2 (D E)	3/4 (A)	2/3 (E)
4	4	3	2	3	2	4	4	Density (% ground covered by wheat)	2	2 (G)	2 (E) E	3/4 (A)	2/3 (E)
4	4	2	2	2	4	3	2	Wind (direction and velocity)	4	4	4	3/4	4

Legend

1 Sufficient
2 Major Contribution
3 Contribution
4 Slight to No Contribution

Letters refer to coded explanation on following page

EXHIBIT IV-6 WHEAT RUST CASE - EARLY OPERATIONAL SYSTEM

MANAGEMENT AREAS/BENEFITS

MEASUREMENTS	Crop Identification	Crop Area and Location	Crop Vigor	Stress Identification	Stress Severity	Stress Location	Infection Probabilities	SENSORS: TV	MSS	Radar	MWR	IR Scanner
Increased Yields	3	3	2	2	2	2	2					
Minimum Daily Temperature	4	4	3	3	3	3	2	4	1/2 (H)		4 (A H)	1/2 (H)
Maximum Daily Temperature	4	4	3	3	3	3	2	4	1/2 (H)		4 (A H)	1/2 (H)
Rainfall	4	4	2	4	4	2	2	3 (B C I)	2 (B C I)	1/2 (B C I S)	2/3 (A B C I)	2/3 (B C I)
Soil Moisture	4	4	3	3	2	2	2	3 (B C)	2 (B C)	2 (B C)	2/3 (A B C)	2/3 (B C)
Plant Temperature	2	2	2	2	2	2	4	4	1/2 (A F)	4	3/4 (A)	1/2 (A F)
Respiration	3	3	3	2	2	2	2	4	4	4	4	4
Evapotranspiration	3	3	2	2	2	2	2	4	2 (A K)	4	3/4 (A,K)	2 (A K)
Acres of Wheat	1	1	4	4	4	4	4	2 (D,G)	2 (F G)	2/3 (D E)	3/4 (A)	3 (E)
Wind (direction and velocity)	4	4	4	4	3	2	2	4	4	3/4	3/4	4

Legend
1 Sufficient
2 Major Contribution
3 Contribution
4 Slight to No Contribution

Letters refer to coded explanation on following page

CODES USED IN EXHIBITS IV-1 THROUGH IV-6

A	Too low a spatial resolution
B	Can detect but not quantify
C	On the basis of area extent only
D	On the basis of low resolution shape information
E	Insufficient resolution for identification by shape and insufficient spectral information
F	Would be excellent if sufficient spatial resolution were possible
G	On the premise of spectral recognition
H	High frequency observation required
I	After fall of rain
J	During fall of rain at time of passage
K	Depending on time of diurnal cycle, transpiration controls plant temperature
L	Could detect wet versus dry soil
M	Could detect heavy rain
N	Obscured by clouds
O	Limited swath width
P	Thermal infrared channel
Q	Qualitative indication
R	Inference from cloud cover
S	Better resolution offers improvement
T	Better resolution would improve interpretability or discriminability
U	Improved discrimination, technique, accuracy, or interpretability

EXHIBIT IV-7 ESTIMATED DEGRADATION IN CONFIGURATION AND BENEFITS IN SUBSTITUTING ERTS FOR ADVANCE I SATELLITE SYSTEM

	Advanced I	ERTS
Resolution		
MSS	1200'	1200'
TV	100'	300'
Radar	50'	None
No. of satellites	4	1
Frequency of observations	1/4 day	7 days
Benefits - Inventory/yield	Percent Degraded from Advanced	
CCC Savings		10
Lower Unit Costs		10
Agri-business		10
Foreign Assistance		
GDP in Less Dev Countries		10
Producers options		75
Benefits - Rust		
Increased Yield		85
Benefits - Hydrology		
Drawdown-refill strategy		75
Hedge		75
Inter-reservoir coordination		75
Head efficiencies		90
Flood Control		90
Irrigation		75
Recreation		75

V CONCLUSIONS

(S) This report studied three cases of satellite-assisted information systems applied to earthbound management systems The three cases involved regional water management, the management of wheat production, and the control of wheat rust and other fungi diseases These three cases can be considered both separately and as interrelated components of a multipurpose satellite-assisted information system

Exhibit V-1 summarizes the total costs and benefits for the satellite-assisted system applied to the three cases studied The costs are broken down into three major components research and development, investment, and annual operating costs The total for the 1971-90 period is $1 34 billion About 50 percent of this is to be found in annual operating costs and another one-fourth is to be found in investment and R&D, respectively A complete discussion of costs is contained in the Cost Appendix It appears that no basic research is required but developmental research will be required in several areas The first research area will be proving that the operation of the multispectral scanner, TV, and radar at satellite altitude will result in expected identification and resolution and measurement accuracies The second research area will be concerned with developing appropriate submodels in the earth sciences to support the integrated system The third will be developing data acquisition and transmission and automatic data interpretation procedures Finally, some development work will be required in processing, rectification and orientation, building the historical data bank, and decision analysis

If this system were employed and used to manage the three systems studied in this report, the 20-year benefits to the United States would be approximately $9.6 billion. If world benefits can be realized, they would add about $50 billion in benefits

Considering the three cases separately, each of the benefit areas could support the total cost of the satellite-assisted system as

Costs[1]	U.S		World
Research and Development		0 34	
Earth Sciences	0 07		
Sensor	0 14		
Sensor Data Acquisition and Transmission	0.05		
Processing, Rectification, Orientation	0 02		
Automatic Data Interpretation	0 05		
Historical Data Bank	0 00		
Decision Analysis	0.01		
Investment		0.36	
Operating		0 64	
Satellite-Assisted System Total[3]		1 34	
Benefits[4]		**U S**	**World**
Water Management		6 3	34
Control of Wheat Rust		1.0	5
Wheat Inventory/Yield		1 5	6
Total Benefits for Three Applications		8 8	45

EXHIBIT V-1 - TOTAL SATELLITE-ASSISTED INFORMATION SYSTEM COSTS AND BENEFITS DISCOUNTED AT 10%, 1971-1990 (Billions of Dollars)

summarized in Exhibit V-1 The four-satellite system proposed in the present report for water management could be employed to manage wheat production If a satellite system were deployed solely for wheat production management, the benefits in this area can, however, be obtained by using fewer satellites and possibly avoiding the use of satellite-borne radar The benefit of the system to the United States would largely accrue from our ability to monitor the total world small grain situation to permit optimal United States adjustments

The wheat rust case is the next most expensive case since it can effectively use radar and requires observations every 12 hours in contrast to observations every 24 hours or more in the wheat production case In this case, the benefits accruing to the United States require overflights only over the United States, Mexico, and possibly Canada The areas to be surveyed, the period of the survey, and the complexity of the sensor package all affect the costs It appears that aircraft offer a lower cost alternative than a satellite system solely for wheat rust control (See Exhibit V-2) However, even in this case, permission for aircraft overflights might be denied by foreign countries.

The water management case is clearly the most expensive, requiring 6-hour coverage It requires the use of radar which will present major technological, weight, and power problems in the satellite In this case, however, the cost-benefit ratios are substantial and the satellite is superior to the aircraft and other alternatives studied if a major portion of the total water regions in the United States are covered In this case, it would not be necessary to survey areas outside the United States to justify the system

The foregoing paragraphs treated the three cases separately The best route is to consider a multipurpose satellite-assisted information system employing a single constellation of satellites configured to cope with the most difficult case

The multipurpose satellite system could be configured to satisfy the water management case which requires observations every

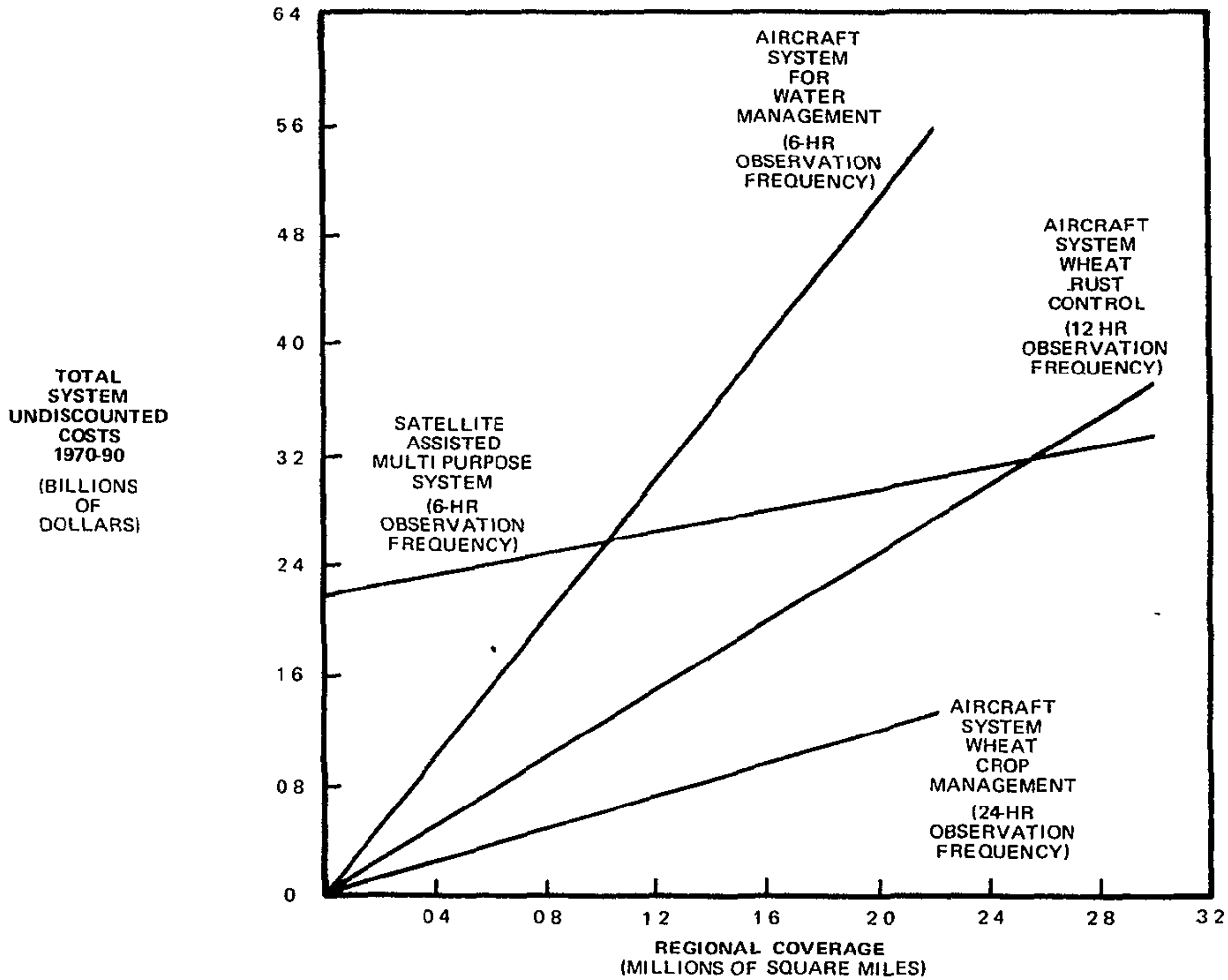

EXHIBIT V-2 SATELLITE AND AIRCRAFT INFORMATION SYSTEM COST/ PERFORMANCE SUMMARY COMPARISON

6 hours and the total sensor package, including MSS, TV, and radar This system also would generate all the information required for the two agricultural cases The telemetering, processing, and dissemination to users can be readily performed within the times required for user decision-making Thus, the satellite-assisted system which could be justified for water management in four out of six major regions in the United States could generate as by-products the benefits from the agricultural cases here and abroad In all likelihood, some system can be extended to other cases not studied in this report, but susceptible to benefits from such a satellite-assisted information system

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